THE CHEMISTRY OF SOILS AND FERTILIZERS

SNYDER

H. P. Armsby.

THE CHEMISTRY

OF

SOILS AND FERTILIZERS

BY

HARRY SNYDER, B.S.,

Professor of Agricultural Chemistry, University of Minnesota,
and Chemist of the Minnesota Agricultural
Experiment Station.

EASTON, PA.:
THE CHEMICAL PUBLISHING COMPANY.
1899.

PREFACE

For several years courses of instruction have been given at the University of Minnesota to classes of young men who intend to become farmers and who desire information that will be of assistance to them in their profession. In giving this instruction mimeographed notes have been prepared, but the increase in the number of students and the volume of notes have necessitated the publication of this work. In its preparation, it has been the aim to give, in condensed form, the principles of chemistry which have a bearing upon the conservation of soil fertility and the economic use of manures.

HARRY SNYDER.

UNIVERSITY OF MINNESOTA,
COLLEGE OF AGRICULTURE,
ST. ANTHONY PARK, MINN.

April 15, 1899.

CONTENTS

INTRODUCTION

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

THE CHEMISTRY OF

SOILS AND FERTILIZERS

INTRODUCTION

Prior to 1800 but little was known of the sources and importance of plant food. Manures had been used from the earliest times, and their value was recognized, but the fundamental principles underlying their use were not understood. It was believed that they acted in some mysterious way. The alchemists had advanced various views regarding their action; one was that the so-called "spirits" left the decaying manure and entered the plant, producing more vigorous growth. As evidence, the worthless character of leached manure was cited. It was believed that the spirits had left such manure. The terms 'spirits of hartshorn', 'spirits of niter', 'spirits of turpentine', and many others reflect these ideas regarding the composition of matter.

Before the composition of plant and animal bodies was established, it was believed that one substance, like copper, could be changed to another substance, as gold. Plants were supposed to be water transmuted in some mysterious way directly into plant tissue. Van Helmont, in the seventeenth century, attempted to prove this. "He took a large earthen vessel and filled it with 200 pounds of dried earth. In it he planted a willow weighing five pounds, which he duly watered with rain and distilled water. After five years he pulled up the willow and it now weighed one hundred and sixty-nine pounds and three ounces."[1] He concluded that 164 pounds of roots, bark, leaves, and branches had been produced by the direct transmutation of the water.

It is evident from the preceding example that anything like an adequate idea of the growth and composition of plant bodies could not be gained until the composition of air and water were established.

The discovery of oxygen by Priestley in 1774, of the composition of water by Cavendish in 1781, and of the rôle which carbon dioxide plays in plant and animal life by DeSaussure and others in 1800, form the nucleus of our present knowledge regarding the sources of matter stored up in plants. It was from 1760 to 1800 that alchemy lost its grip and the way was prepared for the development of modern chemistry.

The work of DeSaussure, entitled "Recherches sur la Vegetation," published in 1804, was the first systematic work showing the sources of the compounds stored up in plant bodies. He demonstrated, quantitatively, that the increase in the amount of carbon, hydrogen, and oxygen, when plants were exposed to sunlight, was at the expense of the carbon dioxide of the air, and of the water of the soil. He also maintained that the mineral elements derived from the soil were essential for plant growth, and gave the results of the analyses of many plant ashes. He believed that the nitrogen of the soil was the main source of the nitrogen found in plants. These views have since been verified by many investigators, and are substantially those held at the present time regarding the fundamental principles of plant growth. They were not, however, accepted as conclusive at the time, and it was not until nearly a half century later, when Boussingault, Liebig, and others repeated the investigations of DeSaussure, that they were finally accepted by chemists and botanists.

From the time of DeSaussure to 1835, scientific experiments relating to plant growth were not actively prosecuted, but the scientific facts which had accumulated were studied and attempts were made to apply the results to actual practice. Among the first to see the relation between chemistry and agriculture was Sir Humphry Davy. In 1813 he published his "Essentials of Agricultural Chemistry", which treated of the composition of air, soil, manures, plants, and of the influence of light and heat upon plant growth. About this same period, Thaer published an important work entitled "Principes Raisonnes d' Agriculture". Thaer believed that humus determined the fertility of the soil, that plants obtained their food mainly from humus, and that the carbon compounds of plants were produced from the organic carbon compounds of the soil. This gave rise to the so-called humus theory, which was later shown to be an inaccurate idea regarding the source of plant food. The writings of Thaer were of a most practical nature, and they did much to stimulate later investigations.

About 1830 there was a renewed interest in scientific investigations relating to agriculture. At this time Boussingault became actively engaged in agricultural research. He was the first to establish a chemical laboratory upon a farm and to make practical investigations in connection with agriculture. This marks the establishment of the first agricultural experiment station. Boussingault's work upon the assimilation of the free nitrogen of the air is reviewed in Chapter IV. His study of the rotation of crops was a valuable contribution to agricultural science. He discovered many important facts relating to the chemical characteristics of foods, and was the first to make a comparative study of the amount of nitrogen in different kinds of foods and to determine the value of foods on the basis of the nitrogen content. His study of the production of saltpeter did much to prepare the way for later work on nitrification. The work of Boussingault covered a variety of subjects relating to plant growth. He repeated and verified much of the earlier work of DeSaussure, and also secured many additional facts relating to the chemistry of crop growth. As to the source of nitrogen in crops, he states that: "The soil furnishes the crops with mineral alkaline substances, provides them with nitrogen, by ammonia and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilizing by the effect of time." As for the absorption of the gaseous nitrogen of the air by vegetable earth, he says: "I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off."[2]

The investigations of DeSaussure and Boussingault, and the writings of Davy, Thaer, Sprengel, and Schübler prepared the way for the work and writings of Liebig. In 1840 he published "Organic Chemistry in its Applications to Agriculture and Physiology". Liebig's agricultural investigations were preceded by many valuable discoveries in organic chemistry, which he applied directly in his interpretations of agricultural problems. His writings were of a forcible character and were extremely argumentative. They provoked, as he intended, vigorous discussions upon agricultural problems. He assailed the humus theory of Thaer, and showed that humus was not an adequate source of the plant's carbon. In the first edition of his work he showed that farms from which certain products were sold naturally became less productive, because of the loss of nitrogen. In a second edition he considered that the combined nitrogen of the air was sufficient for crop production. He overestimated the amount of ammonia in the air, and underestimated the value of the nitrogen in soils and manures. A study of the composition of plant-ashes led him to propose the mineral theory of plant nutrition. De-Saussure had shown that plants contained certain mineral elements, but he did not emphasize their importance as plant food. Liebig's writings on the composition of plant-ash, and the importance of supplying crops with mineral food led to the commercial preparation of manures, which in later years has developed into the commercial fertilizer industry. The work of Liebig was not conducted in connection with field experiments. It had, however, a most stimulating influence upon investigations in agricultural chemistry, and to him we owe, in a great degree, the summarizing of previous disconnected work and the mapping out of valuable lines for future investigations.

Liebig's enthusiasm for agricultural investigations may be judged from the following extract: "I shall be happy if I succeed in attracting the attention of men of science to subjects which so well merit to engage their talents and energies. *Perfect agriculture is the true foundation of trade and industry ; it is the foundation of the riches of states.* But a rational system of agriculture cannot be formed without the application of scientific principles; for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils, and actions of manures upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of the study of the character of the different substances from which plants derive their nourishment."[3]

Soon after Liebig's first work appeared the investigations at Rothamsted by Sir J. B. Lawes were undertaken. The most extensive systematic work in both field experiments and laboratory investigations which have ever been conducted have been carried on by Lawes and Gilbert at Rothamsted, Eng. Dr. Gilbert had previously been a pupil of Liebig, and his association with Sir J. B. Lawes marked the establishment of the second experiment station. Many of the Rothamsted experiments have been continued since 1844, and results of the greatest value to agriculture have been obtained. The investigations on the non-assimilation of the atmospheric nitrogen by crops, published in 1861, were accepted as conclusive evidence upon this much-vexed question. The work on manures, nitrification, the nitrogen supply of crops, and on the increase and decrease of the nitrogen of the soil when different crops are produced, has had a most important bearing upon maintaining the fertility of soils.

"The general plan of the field experiments has been to grow some of the most important crops of rotation, each separately, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures, the same kind of manure being, as a rule, applied year after year on the same plot. Experiments with different manures on the mixed herbage of permanent grass land, on the effects of fallow, and on the actual course of rotation without manure, and with different manures have likewise been made." [4]

In addition to Davy, Thaer, DeSaussure, Boussingault, Liebig, and Lawes and Gilbert, a great many others have contributed to our knowledge of the chemistry of soils. The work of Pasteur, while it did not directly relate to soils, indirectly had a great influence upon soil investigations. His researches upon fermentation made it possible for Schlösing to prove that nitrification was the result of the workings of living organisms which have since been isolated and studied by Warington and Winogradsky.

Many of the more recent investigations relating to the chemistry of soils are reviewed in the following chapters. Our knowledge regarding the chemistry, physics, geology, and bacteriology of soils is at the present time far from complete, but many facts have been discovered which are of the greatest value to the practical farmer. Of late years investigations relating to the chemistry of soils and fertilizers have become so extensive that the term 'agronomy' has been used to designate that part of agricultural chemistry.

In soil investigations it has frequently happened, owing to imperfect interpretation of results and to the presence of many modifying influences, that the results and conclusions of one investigator appear to be directly contradictory to those of another. This is well illustrated in the investigations relating to the assimilation of the free atmospheric nitrogen, in which seemingly opposite conclusions now form a complete theory.

CHAPTER I

PHYSICAL PROPERTIES OF SOILS

1. **Soil.** — Soil is disintegrated and pulverized rock mixed with animal and vegetable matter. The rock particles are of different kinds and sizes, and are in various stages of decomposition. If two soils are formed from the same kind of rock and differ only in the size of the particles, the difference is merely a physical one. If, however, one soil is formed largely from sandstone, while the other is formed from limestone, the difference is both physical and chemical. Hence it is that soils differ both physically and chemically. It is difficult to consider the physical properties of a soil without also considering the chemical properties. The chemical and physical properties of a soil, when jointly considered, determine largely its agricultural value.

2. **Physical Properties Defined.** — The physical properties of a soil are:

1. Weight.
2. Color.
3. Size, form, and arrangement of the soil particles.
4. The relation of the soil to water, heat, and cold.
5. The relation of the soil to electricity.
6. Odor and taste.

3. Weight.—Soils differ in weight according to the composition and size of the particles. Fine sandy soils weigh heaviest, while peaty soils are lightest in weight. But when saturated with water, a cubic foot of peaty soil weighs more than a cubic foot of sandy soil. Clay soils weigh less per cubic foot than sandy soils. The larger the amount of organic matter in a soil the less the weight. Pasture land, for example, weighs less per cubic foot than arable land. Weight is an important property to consider when the total amounts of plant food in two soils are compared. For example, a peaty soil containing 1 per cent. of nitrogen and weighing 30 pounds per cubic foot has less total nitrogen than a soil containing 0.40 per cent. of nitrogen and weighing 80 pounds per cubic foot.

(1) The weight of soils per cubic foot is approximately as follows: [5]

	Pounds.
Clay soil	70 to 75
Fine sandy soil	95 to 110
Loam soil	75 to 90
Peaty soil	25 to 60
Average prairie soil	75
Uncultivated prairie soil	65

Figures for the weight per cubic foot or specific gravity of soils are on the basis of the dry soil. When taken from the field the weight per cubic foot varies with the amount of water present.

(2) The volume of a soil varies with the conditions

to which it has been subjected. Usually about 50 per cent. of the volume of a soil is air space. A cubic foot of soil from a field which has been well cultivated weighs less than from a field where the soil has been compacted. Hence it is that soils have both a real and an apparent specific gravity. The apparent specific gravity of a soil is sometimes less than half of the real specific gravity. The specific gravity of different soils as given by Shöen is as follows:[6]

	Specific gravity.
Clay soil	2.65
Sandy soil	2.67
Fine soil	2.71
Humus soil	2.53

4. Size of the Soil Particles.—The size of the soil particles varies from those hardly distinguishable with the microscope to coarse rock fragments. The size of the particles determines the character of the soil as sandy, clay, or loam. The term 'fine earth' is used to designate that part of the soil which passes through a sieve with holes 0.5 mm. (0.02 inch) in diameter. Coarse sand particles and rock fragments which fail to pass through the sieve are called skeleton. The amount of fine earth and skeleton is variable. Arable soils, in general, contain from 5 to 20 per cent. of skeleton.

The fine earth is composed of six grades of soil particles. The names and sizes are as follows:

	Millimeters.		Inches.	
Medium sand......	0.5	to 0.25	0.02	to 0.01
Fine sand..........	0.25	to 0.1	0.01	to 0.004
Very fine sand.....	0.1	to 0.05	0.004	to 0.002
Silt	0.05	to 0.01	0.002	to 0.0004
Fine silt...........	0.01	to 0.005	0.0004	to 0.0002
Clay	0.005 and less		0.0002 and less	

Soils are mechanical mixtures of various sized particles. In most soils there is a predominance of one grade, as clay in heavy clay soils, and medium sand in sandy soils. No soil, however, is composed entirely of one grade. The clay particles are exceedingly small; it would take 5000 of the larger ones, if laid in a line with the edges touching, to measure an inch, while it would take but 50 of the larger medium sand particles to measure an inch.

5. Clay. — The term clay used physically denotes those soil particles less than 0.005 mm. (0.0002 inch) in diameter, without regard to chemical composition. As used in a physical sense clay may be silica, feldspar, limestone, mica, kaolin, or any other rock or mineral which has been pulverized until the particles are less than 0.005 mm. in diameter. Chemically, however, the term clay is restricted to one material, as will be explained in another part of the work. The physical properties of clay are well known. It has the power of absorbing a large amount of water, and will remain suspended in water for a long time. The roiled appearance of many streams and lakes is due to the presence of suspended clay particles. The amount in agricultural soils may range from 3 to 50 per cent. Clay soils, if worked when too wet, become puddled; then percolation cannot take place, and the accumulated surface water must be removed by the slow process of evaporation.

6. Silt.—The silt particles are, in size, between sand and clay. Many of the western prairie subsoils, clay-like in nature, are composed mainly of silt. The silt imparts characteristics intermediate to sand and clay. While a clay soil is nearly impervious to water, and when wet works with difficulty, a silt soil is more permeable, but is not as open and porous as a sandy soil. When a soil containing large amounts of clay and silt is treated with water, the silt settles slowly, while the clay remains in suspension. The fine deposit in ditches and drains, where the water moves slowly, is mainly silt.

7. Sand. — There are three grades of sand. The characteristics, as permeability and non-cohesion of particles, are so well known that they do not require discussion. A soil composed entirely of sand would have little, if any, agricultural value. Sandy soils usually contain from 5 to 15 per cent. of clay and silt. The relative sizes of sand, silt, and clay are given in the illustration.

8. Form of Soil Particles. — Soil particles are extremely varied in form. When examined with the microscope they show the same diversity as is observed in larger stones. In some soils the particles are spherical, while in others they are angular. The shape

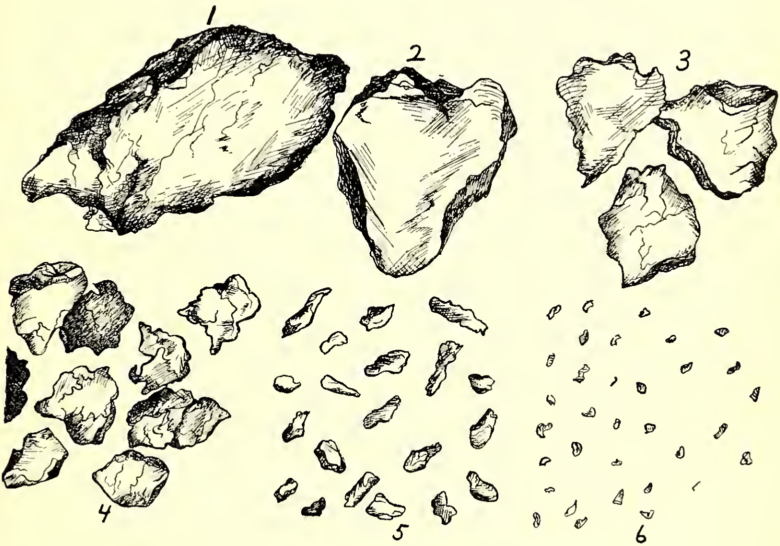


Fig. 1. Medium Sand × 150. Fig. 2. Fine Sand × 150. Fig. 3. Very Fine Sand × 150. Fig. 4. Silt × 325. Fig. 5. Fine Silt × 325. Fig. 6. Clay × 325.

of the particles is determined by the way in which the soil has been formed and also by the nature of the rock from which it was produced.

The form and arrangement of the particles are important factors to consider in dealing with the water content of soils. In the wheat lands of the Red River Valley of the North, the particles are small and spherical, being formed largely from limestone rock, while the subsoil of the western prairie regions is composed largely of angular silt particles, which are intermingled with clay, forming a mass containing only a minimum of inter soil spaces. The silt particles being angular and imbedded in the clay, the soil has more the character of clay than of silt. While these two soils are unlike in physical composition, the form and arrangement of the particles give each nearly the same water-holding power. On account of a difference in the form and arrangement of the soil particles two soils may have the same mechanical composition, and yet possess materially different physical properties. In some soils 10 per cent. of clay is of more value agriculturally than in other soils. Ten per cent. of clay associated with 60 or 70 per cent. of silt, makes a good grain soil, while 10 per cent. of clay associated largely with sand makes a soil poorly suited to grain culture.

The classification of the soil particles into sand, silt, and clay is purely an arbitrary one. Various authors use these terms in different ways, and when comparing soils, reported in different works, one may avoid confusion by omitting the names and noting only the sizes of the particles. A division has recently been suggested by Hopkins[7] in which the square root is often taken as the constant ratio between the grades of soil particles.

9. Number of Particles per Gram of Soil. — It has been estimated that a gram of soil contains from 2,000,000,000 to 20,000,000,000 soil particles; soils which contain less than 1,700,000,000 are unproductive. The number of particles in a given volume of soil varies with their size and form. According to Whitney[8] the number of particles per gram of different soil types is as follows:

Early truck	1,955,000,000*
Truck and small fruit	3,955,000,000
Tobacco	6,786,000,000
Wheat	10,228,000,000
Grass and wheat	14,735,000,000
Limestone	19,638,000,000

Assuming that the particles are all spheres, it is estimated that in a cubic foot of soil a surface area of from two to three and one-half acres is presented to the action of the roots.

10. Methods Employed in Separating Soil Particles. — Sieves with circular holes 0.5, 0.25, and 0.1 mm. are employed for the purpose of separating the three coarser grades of sand. The sieve *a*, 0.5 mm. size, is connected with the filtering flask *c* by means of the tube *b*, and the flask is connected at point *d* with a suction-pump. Ten grams of soil, after treatment with

* Figures below sixth place omitted and ciphers substituted.

boiling water, are placed in the sieve. Water is passed through until the washings are clear. All particles larger than 0.5 mm. remain in the sieve, and after drying and igniting, are weighed. The contents of flask *c*, containing the particles less than 0.5 mm., are then passed through a sieve having holes 0.25 mm. in diameter. Finally a 0.10 mm. diameter sieve is used.

The fine sand and silt are separated by gravity. The fine sand with some silt and clay are readily deposited and the water containing the suspended clay is decanted into a second glass vessel. The residue is treated with more water and allowed to settle; this operation is repeated until the microscope shows the soil particles to be nearly all of one grade.

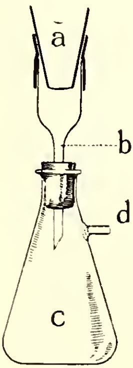
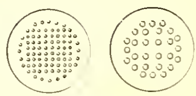


Fig. 7.

Clay is obtained by evaporating an aliquot portion of the washings or by determining the total per cent. of the other grades of particles and the volatile matter and subtracting the sum from 100. This is the Osborne sedimentation method with modifications.[9] Hilgard's[10] elutriator, and the apparatus of Shoen-Mayer are also used for separating the soil particles.


Figs. 8 and 9.

SOIL TYPES

11. **Crop Growth and Physical Properties.** — The

preference of certain crops for particular kinds of soil, as wheat for a clay subsoil, potatoes for a sandy soil, and corn for a silt soil, is due mainly to the peculiarities of the crop in requiring definite amounts of water, and a certain temperature for growth. These conditions are met by the soil being composed of various grades of particles which enable a certain amount of water to be retained, and the soil to properly respond to the influences of heat and cold. In considering soil types, it should be remembered that there are so many conditions influencing crop growth that the crop-producing power cannot always be determined by a mechanical analysis of the soil. The following types have been found to hold true in a large number of cases under average conditions, but they do not represent what might be true of a case under special conditions. For example a sandy soil of good fertility in which the bottom water is only a few feet from the surface, may produce larger grainc rops than a clay soil in which the bottom water is at a greater depth. In judging the character of a soil, special conditions must always be taken into consideration. In discussing the following soil types, a normal supply of plant food and an average rainfall are assumed in all cases.

12. Potato and Early Truck Soils. — The better types of potato soils are those which contain about 60 per cent. of medium sand, 20 to 25 per cent. of silt, and about 5 per cent. of clay. Soils of this nature when supplied with about 3 per cent. of organic matter will contain from 5 to 12 per cent. of water. The best conditions for crop growth exist when the soil contains from 5 to 7 per cent. of water. In a sandy soil vegetation may reduce the water to a much lower point than in a clay soil. On account of sandy soil giving up its water so readily to growing crops nearly all is available, while on heavy clay, crops show the want of water when the soil contains from 7 to 8 per cent., because the clay holds the water so tenaciously. When potatoes are grown on soils where there is an abnormal amount of water the crop is slow in maturing. For early truck purposes in northern latitudes, sandy soils are the most suitable because they warm up more readily, and the absence of an abnormal amount of water results in early maturity. Excellent crops of potatoes are grown on many of the silt soils of the west which have a materially different composition from the type given. A soil may have all of the requisites physically for the production of good potato and truck crops, and still be unproductive on account of some peculiarity in chemical composition.

13. General Truck and Fruit Soils. — For fruit growing and general truck purposes the soil should contain more clay and less sand than for early truck farming. Soils containing from 10 to 15 per cent. of clay and not more than 40 per cent. of sand are best suited for growing small fruits. Such soils will retain from 10 to 18 per cent. of water. There is a noticeable difference as to the adaptability of different kinds of fruit to different soils. Some fruits thrive on clay land, provided the proper cultivation and treatment are given. There is as much diversity of soil, required for producing different fruit crops as for the production of different farm crops. As a rule, however, a silt soil is most capable of being adapted to the various conditions required by fruit crops.

14. **Corn Soils.** — The strongest types of corn soils are those which contain from 40 to 45 per cent. of medium and fine sand and about 15 per cent. of clay. Corn lands should contain about 15 per cent. of available water. Heavy clays produce corn crops which mature later than those grown on soils not so close in texture. Many corn soils contain less sand and clay, but more silt than the figures given. If the soil contains a high per cent. of organic matter, good corn crops may be produced where there is less than twelve per cent. of clay. Soils containing a high per cent. of sand are usually too deficient in available water to produce a good crop. On the other hand heavy clay soils are slow in warming up and are not suited to corn culture.

The strongest types of corn soils have the proper mechanical composition for the production of good crops of sorghum, cotton, flax, and sugar-beets. However, the amount of available plant food required for each crop is not the same. The western prairie soils which produce most of the corn raised in the United States, are composed largely of silt.

15. Medium Grass and Grain Soils. — For the production of grass and grain a larger amount of water is required than for corn. The yield of both is determined largely by the amount of water which the soil contains. For an average rainfall of about 30 inches, good grass and grain soils should contain about 15 per cent. of clay and 60 per cent. of silt. Such a soil ordinarily holds from 18 to 20 per cent. of water. Many grass and grain soils have less silt and more clay. A soil composed of about 30 per cent. each of fine sand, silt, and clay, would also be suitable, mechanically, for general grain production. There are a number of different types of grass and grain soils, with different proportional amounts of sand, silt, and clay. Silt soils, however, form the larger part of the grain soils of the United States.

16. Wheat Soils. — For wheat production, soils of a closer texture are required than for general grain farming. There are three classes of wheat soils. The first (1 in Fig. 10) contains from 30 to 50 per cent. of clay particles, these being mostly disintegrated limestone. The soil of the Red River Valley of the North belongs to the first class of wheat-producing soils. The surface soil contains from 8 to 12 per cent. of vegetable matter and the subsoil about 25 per cent. of limestone in a very fine state of division. For the production of wheat the subsoil should contain 20 per cent. of water. A crop can, however, be produced with less water, but a smaller yield is obtained.

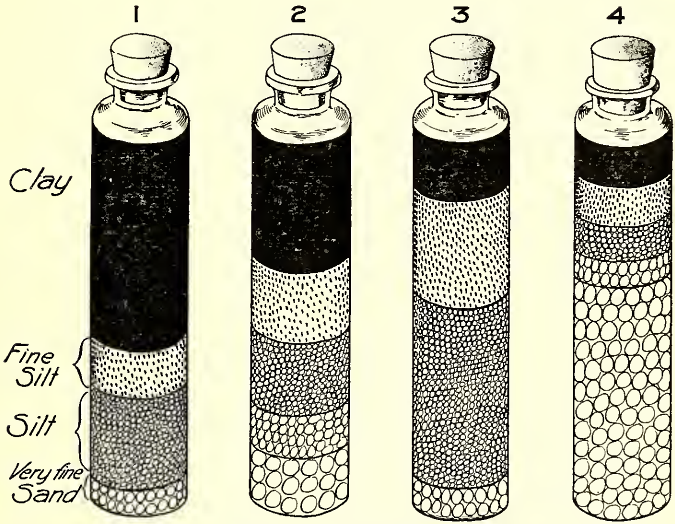


Fig. 10. Soil types.

The second type of wheat soil (2 in Fig. 10) contains less clay and more silt. Many prairie subsoils which produce good crops of wheat contain about 20 per cent. of sand, 50 per cent. of silt, and from 20 to 30 per cent. of clay. Soils of this class when well stocked with moisture in the spring are capable of producing good crops of wheat, but are not able to withstand drought so well as soils of the first class.

To the third class of wheat soils (3 in Fig. 10) belong those which are composed mainly of silt, containing usually 75 per cent., and from 10 to 15 per cent. of clay. The high per cent. of fine silt gives the soil clay-like properties. Soils of this class are adapted to a great variety of crops. For the production of wheat on silt soils it is very essential that a good supply of organic matter be kept in the soil so as to bind together the soil particles. The special peculiarities of the different grain crops as to soil requirements will be considered in connection with the food requirements of crops.

17. Sandy, Clay, and Loam Soils. — In ordinary agricultural literature the term 'sandy,' 'clay,' or 'loam' is used to designate the prevailing character of the soil. Sandy soils usually contain 90 per cent. or more of silica or chemically pure sand. The term light sandy soil is sometimes used to indicate that the soil is easily worked, while the term heavy clay means that the soil offers great resistance to cultivation. Many soils which are clay-like in character are not composed very largely of clay. There are subsoils in the western states which have clay-like characteristics but contain only about 15 per cent. of clay, the larger part of the soil being silt. A loam soil is a mixture of sand and clay; if clay predominates the soil is a clay loam, while if sand predominates it is a sandy loam.

18. Amount of Water Required by Crops. — Experiments have shown that it takes from 275 to 375 pounds of water to produce a pound of dry matter in a grain crop. In order to produce an average acre of wheat 350 tons of water are needed. The amount of water required for the production of an average acre of various crops is as follows: [11]

	Average amount. Tons water.	Minimum amount. Tons water.
Clover	400	310
Potatoes	400	325
Wheat	350	300
Oats	375	300
Peas	375	300
Corn	300	...
Grapes	375	...
Sunflowers[6]	6000	...

The rainfall during the time of growth is frequently less than the amount of water required for the production of a crop. An average rainfall of 2 inches per month during the three months of crop growth would be equivalent to only 369 tons of water per acre, a variable part of which is lost by evaporation. Hence it is that the rainfall during an average growing season is less than the amount of water required, and in order to produce crops, the water stored up in the soil must be drawn upon to a considerable extent. Inasmuch as the soil's reserve supply of water is such an important factor in crop production, it follows that the capacity of the soil for storing up water and giving it up as needed is a matter to be considered, particularly since the power of the soil for absorbing and retaining water may be influenced by cultivation and manuring. Before discussing the influence of cultivation upon the soil water, the forms in which it is present in the soil should be studied. Water is present in soils in three forms: (1) bottom water, (2) capillary water, and (3) hydroscopic water.

19. Bottom Water is water which stands in the soil at a general level, and fills all the spaces between the soil particles. Its distance from the surface can be told in a general way by the depth of surface wells. Bottom water is of service to growing crops when it is

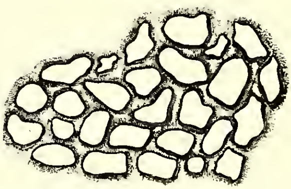


Fig. 11. Water films surrounding soil particles.

at such a depth that it can be brought to the plant roots by capillarity, but when near the surface so that the roots are immersed, very poor conditions for crop growth exist. When the bottom water can be brought within reach of the roots by capillarity a crop has an almost inexhaustible supply. In many soils known as old lake bottoms such conditions exist.

20. Capillary Water. — The water held in the capillary spaces above the bottom water is known as the capillary water. The capillary spaces of the soil are the small spaces between the soil particles in which water is held by surface tension; that is, the force acting between the soil and the water is greater than the force of gravity. If a series of glass tubes of different diameters be placed in water it will be observed that in the smaller tubes water rises much higher than in the larger. The water rises in all of

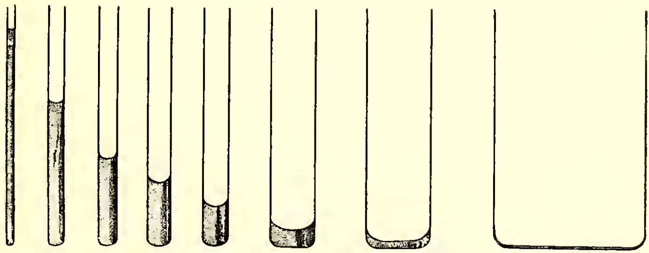


Fig. 12. Comparative height to which water rises in glass tubes.

the tubes until a point is reached where the force of gravity is equal to the force of surface-tension. In the smaller tubes surface-tension is greater than the force of gravity, and the water is drawn up into the tube. In the larger tubes the surface-tension is less and water is raised only a short distance. There are present in the soil many spaces which are capable of taking up water in the same way as the small glass tubes. The height to which water can be raised by capillarity depends upon the size and arrangement of the soil particles. Water may be raised by capillarity to a height of several feet. Ordinarily, however, the capillary action of water is confined to a few feet. The arrangement of the soil particles influences greatly the capillary power of the soil. Usually from 30 to 60 per cent. of the bulk of a soil is air space: by compacting, the air spaces may be decreased; by stirring, the air spaces are increased. In some soils of a close texture an increase in air spaces results in an increase of capillary spaces and of water-holding capacity, while in other soils, as coarse sandy soils, increasing the air spaces decreases the capillary spaces and the water-holding capacity. The best conditions for crop production exist when the soil contains water to the extent of about 40 per cent. of its total capacity of saturation.

21. Hydroscopic Water. — By hydroscopic water is meant the water content of the soil atmosphere. The air which occupies the non-capillary spaces of the soil is charged with moisture in proportion to the water in the soil. Under normal conditions the soil atmosphere is nearly saturated. When soils have exhausted their capillary water, the water in the soil atmosphere is correspondingly reduced. The available supply in other forms being exhausted, the hydroscopic water cannot contribute to plant growth.

22. Loss of Water by Percolation. — Whenever a soil becomes saturated, percolation or a downward movement of the water begins. The extent to which losses by percolation may occur depends upon the character of the soil and the amount of rainfall. When soils are covered with vegetation the losses by percolation are less than from barren fields. In all soils which have only a limited number of capillary spaces and a large number of non-capillary spaces, the amount of water which can be held above the bottom water is small. From such soils the losses by percolation are greater than from soils which have a larger number of capillary spaces, and a smaller number of non-capillary spaces. In coarse sandy soils many of the spaces are too large to be capillary.

If all of the water which falls on some soils could be retained and not carried beyond the reach of crops by percolation, there would be an ample supply for agricultural purposes. To prevent losses by percolation, the texture of the soil may be changed by cultivation and by the use of manures. If the soil is of very fine texture, as a heavy clay, percolation is slow, and before the water has time to sink into the soil, evaporation begins; with good cultivation the water is able to penetrate to a depth beyond the immediate influence of evaporation. Compacting an open porous soil by rolling, checks rapid percolation and prevents the water from being carried beyond the reach of plant roots. In order to prevent excessive losses by percolation, the treatment must be varied to suit the requirements of different soils.

23. Loss of Water by Evaporation. — The factors which influence evaporation are temperature, humidity, and rate of movement of the air. When the air contains but little moisture and is heated and moving rapidly, the most favorable conditions for evaporation exist. In semiarid regions the losses of water by evaporation are much greater than by percolation. The dry air comes in contact with the soil, the soil atmosphere gives up its water, and, unless checked by cultivation, the subsoil water is brought to the surface by capillarity and lost. In porous soils, a greater freedom of movement of the air is possible, which increases the rate of evaporation. When the surface of the soil is covered with a layer of finely pulverized earth, or with a mulch, excessive losses by evaporation cannot take place, because a material of different texture is interposed between the soil and the air.

24. Loss of Water by Transpiration. — Losses of water may also occur from the leaves of plants by the process known as transpiration. Helriegel observed that during some years 100 pounds more water were required to produce a pound of dry matter than in other years, because of the difference in the amount of water lost by transpiration. The loss of water by evaporation can be controlled by cultivation, but the loss by transpiration can be only indirectly influenced. Hot dry winds may cause crops to wilt because the water lost by transpiration exceeds the amount which the plant takes from the soil.

The three ways in which crops are deprived of water are by (1) percolation, (2) evaporation, and (3) transpiration. With proper methods of cultivation, losses by percolation and evaporation may be controlled, and losses by transpiration may be reduced.

INFLUENCE OF CULTIVATION UPON THE WATER SUPPLY OF CROPS

25. Capillarity Influenced by Cultivation. — The capillarity of the soil is subject to change with different methods of cultivation, as rolling and subsoiling, deep plowing and shallow surface cultivation. The method of cultivation which a soil should receive in order to secure the best water supply for crops must vary with the rainfall, the nature of the soil, and the crop to be produced. It frequently happens that the annual rainfall is sufficient to produce good crops, but is too unevenly distributed. It is possible, to a great extent, to vary the cultivation to meet the water requirements of crops.

26. Shallow Surface Cultivation. — When shallow surface cultivation is practiced, the capillary spaces near the surface are destroyed and the direct connection of the subsoil water with the surface is broken. When the soil particles have been disturbed and a layer of finely pulverized earth covers the surface, there is not that close contact which enables the water to pass from particle to particle. When evaporation takes place there is a movement of the subsoil water to the surface, but if the surface is covered with a layer of fine earth, the subsoil water cannot readily pass through such a medium, and evaporation is checked. Hence shallow surface cultivation conserves the soil moisture.

The means by which surface cultivation is accomplished must, of necessity, vary with the nature of the

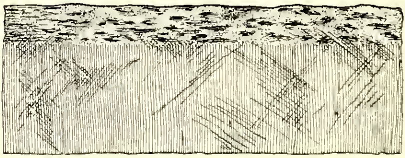


Fig. 13. With surface cultivation.

soil. If a harrow is used the pulverization should be complete. If a disk is used the teeth should be set at an angle, and not perpendicularly, so as to prevent, as

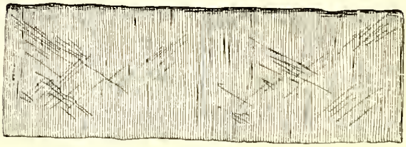


Fig. 14. Without surface cultivation.

suggested by King,[12] the formation of hard ridges which hasten evaporation. When the disk is set at an angle, a layer of soil is completely cut off, and the capillary connection with the subsoil is broken. Surface cultivation should be from two to three inches deep, and the finer the condition in which the surface soil is left, the better.

Shallow surface cultivation should be resorted to as a means of conserving soil moisture. It can be practiced in connection with deep plowing, shallow plowing, subsoiling, or rolling; in fact, it can be combined with any method of preparing the land. Shallow surface cultivation does not mean that the soil should not be previously well prepared by thorough cultivation. The following example shows the extent to which shallow surface cultivation may conserve the soil water.[13]

	Per cent. of water in cornfield.	
	With shallow surface cultivation.	Without shallow surface cultivation.
Soil, depth 3 to 9 inches	14.12	8.02
Soil, depth 9 to 15 inches	17.21	12.38

27. Cultivation after a Rain. — When evaporation takes place immediately after a rain, not only is there a loss of the water which has fallen, but there may also be a loss of the subsoil water by translocation, if nothing be done to prevent.[12] The following example shows the extent to which the subsoil water may be brought to the surface.[13]

	Per cent. of water.	
	Surface soil. 1 to 3 inches.	Subsoil. 6 to 12 inches.
Before the shower	9.77	18.22
After the shower	22.11	16.70

The rainfall was sufficient to have raised the water content of the surface soil to 20.77 per cent. The subsoil showed a loss of 1.52 per cent., while the surface soil showed a gain of 1.34 per cent. in addition to the water received from the shower. If evaporation begins before the equilibrium is reestablished, there is lost, not only the water from the shower, but also the water which has been translocated from the subsoil to the surface. Hence the importance of shallow surface cultivation immediately after a rain.

When a subsoil contains a liberal supply of water, and the surface soil a minimum amount, there is after an ordinary shower a movement of the subsoil water to the surface. The soil particles at the surface are surrounded with films of water which thicken at the expense of the subsoil water. Surface-tension is the cause of this movement of the water to the surface, and under the conditions stated it is temporarily greater than the force of gravity.

A thin hard crust should never be allowed to form after a rain, because it hastens the losses by evaporation, while a soil mulch formed by surface cultivation has the opposite effect.

28. Rolling.—The use of heavy rollers for compacting the soil is beneficial in a dry season on a soil containing large proportions of sand and silt. Rolling the land compacts the soil and improves the capillary conditions, enabling more of the subsoil water to be brought to the surface. Experiments have shown that when land is rolled the amount of water in the surface soil is increased. This increase is, however, at the expense of the subsoil water.[12] Unless rolled land receives surface cultivation excessive losses by evaporation, due to improved capillarity, may result. The use of the roller on clay land during a wet season results unfavorably. In many localities rolling and subsequent surface cultivation are not admissible on account of the drifting of the soil, caused by heavy winds.

29. **Subsoiling.** — By subsoiling is meant pulverizing the soil immediately under the furrow slice. This is accomplished with the subsoil plow, which simply loosens the soil without bringing the subsoil to the surface. The object of subsoiling is to enable the land to retain, near the surface, more of the rainfall. Heavy clay lands are sometimes improved by occasional subsoiling, but its continued practice is not desirable. For orcharding and fruit-growing, it is frequently resorted to, but is not beneficial on soils containing large amounts of sand and silt. Rolling and subsoiling are directly opposite in effect. Soils which are improved by rolling are not improved by subsoiling. The additional expense involved should be considered when subsoiling is to be resorted to. Experiments have not as yet been sufficiently decisive to indicate the conditions most favorable for this practice.

30. **Fall Plowing** conserves the soil water, by checking evaporation and leaving the land in better condition to retain moisture. Fall plowing should be fol-

lowed by surface cultivation. Evaporation may take place from unplowed land during the fall, and in the spring the soil contains appreciably less water than plowed land. By fall plowing it is possible to carry over a water balance in the soil from one year to the next.

31. Spring Plowing. — When land is plowed late in the spring there has been a previous loss of water by evaporation, and the soil has not been able to store up as much of the rain and snow as if fall plowing had been practiced.[14] Dry soil is plowed under and moist soil brought to the surface. This moisture is readily lost by evaporation if surface cultivation is not employed; good capillary connection of the surface soil and subsoil is not obtained, and the furrow slice soon becomes dry.

Surface cultivation should immediately follow both spring and fall plowing.

	Per cent. of water in[13]	
April 25	Fall plowed land.	Spring plowed land.
From 2 to 6 inches	24.7	22.4
" 6 to 12 "	26.6	24.1
" 12 to 18 "	28.8	26.5
Average difference		2.37 per cent.

32. Mulching. — The use of well-rotted manure or straw, spread over the surface as a mulch, prevents evaporation. In forests the leaves form a mulch which is an important factor in maintaining the water supply. In order that a mulch be effectual, it must be compacted,—a loose pile of straw is not a mulch. In reclaiming lands gullied by water, mulching is very beneficial. A slight mulch may also be used to encourage the growth of grass on a refractory hillside. When land is mulched, evaporation is checked. Surface cultivation and mulching may be combined and excellent results obtained.[13]

	Per cent. of water in Mulched strawberry patch.	Unmulched.
Soil 2 to 5 inches............	18.12	11.17
" 6 to 12 "	22.18	18.14
" 12 to 18 "	24.31	21.11

33. Depth of Plowing.—The depth to which a soil should be plowed in order to give the best results must, of necessity, vary with the conditions. Deep plowing of sandy land is not advisable, particularly in the spring. On clay land deeper plowing should be the rule. The longer a soil is cultivated the deeper and more thorough should be the cultivation. While shallow plowing is admissible on new prairie land, deeper cultivation should be practiced when the land has been cropped for a series of years. The depth of plowing should be regulated by the season. In the prairie regions, and in the northwestern part of the United States, shallow plowing is more generally practiced than in the eastern states. Deep plowing in the fall gives better results than in the spring. It is not a wise plan to plow to the same depth every year. Prof. Roberts says:[15] "If plowing is continued at one depth for several seasons, the pressure of the implement and the trampling of the horses in time solidify the bottom of the furrow, but if the plowing is shallow in the spring and deep in summer and fall, the objectional hard pan will be largely prevented."

In regions of scant rainfall deep plowing of silt soils should be done only at intervals of three or five years. With an average rainfall, deep plowing should be the rule on soils of close texture. The depth of plowing should be varied to meet the requirements of the crop, of the soil and the amount of rainfall.

34. Permeability of Soils.—The rapidity with which water sinks into the soil after a rain depends upon the nature of the soil, and upon the cultivation which it has received. Shallow surface cultivation leaves the soil in good condition to absorb water. When the surface is hard and dry a large per cent. of the water which falls on rolling land is lost by surface drainage. Soils of close texture which contain but few non-capillary spaces, offer the greatest resistance to the downward movement of water.

The term permeable is applied to a soil when it is of such a texture that it does not allow the water to accumulate and clog the non-capillary spaces. Cultivation may change the texture of even a clay soil to such an extent as to render it permeable. Deep plowing increases permeability. In regions of heavy rains increased permeability is very desirable for good crop production on heavy clays. Sandy and loamy soils have a high degree of permeability, and it is not necessary that it should be increased.

35. Fertilizers. — When water contains dissolved salts, it is more susceptible to the influence of surface-tension, and is more readily brought to the surface of the soil. In commercial fertilizers soluble salts are present. The beneficial effects of commercial fertilizers upon the moisture content of soils are liable to be overestimated, because the fertilizer undergoes fixation when applied, and does not remain in a soluble condition. Fertilizers containing soluble salts exercise a favorable influence upon the moisture content of soils, but the extent of this influence has never been determined under field conditions.

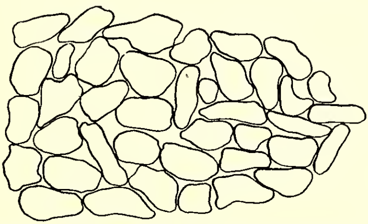


Fig. 15. Sandy soil without manure.

36. Farm Manures. — Well-prepared farm manures exercise a beneficial effect upon the moisture content of soils. When well-rotted manure is worked into a soil, the coarse soil particles and masses are bound together, and the non-capillary spaces are made capillary. The free circulation of the air which increases evaporation, is prevented when a sandy soil is manured. When

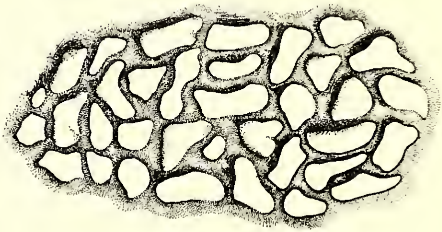


Fig. 16. Sandy soil with manure.

silt and sandy soils are manured they are capable of retaining more water, as shown by the following example:[13]

	Fine sandy soil. Per cent.	95 per cent. fine sandy soil. 5 per cent. dry manure. Per cent.
Capacity for holding water	25	42

The manure enables the soil to retain more water near the surface and prevents losses by percolation. The difference in moisture content of manured and unmanured land is particularly noticeable in a dry season.[13]

	Sandy soil well manured. Water. Per cent.	Sandy soil unmanured. Water. Per cent.
Soil one to six inches	10.50	8.10

Coarse leached manure may have just the opposite effect by producing an open and porous condition of the soil.

37. Drainage.—Good drainage is very essential in order to properly regulate the water supply. If the water which falls on the land is allowed to flow over the surface and is not retained in the soil, there is not sufficient reserve water for crop growth. The object of good drainage is to store up as much water as possible in the subsoil and to prevent surface accumulation and losses. Good drainage is accomplished by thorough cultivation, and in regions of heavy rainfall by tile drainage. Well-drained land is warmer in the spring, has a larger reserve store of water, and is in better condition for crop growth.

38. Influence of Forest Regions.—The deforesting of large areas near the source of rivers has an injurious influence upon the moisture content of adjoining farm lands. By cutting over and leaving barren large tracts, less water is retained in the soil. Near forest regions the air has a higher moisture content, due to the water given off by evaporation. Farm lands adjacent to deforested districts lose water more rapidly by evaporation, because the air is so much drier. In Section 24 it was stated that losses of water by transpiration could be indirectly influenced. This can be accomplished by retaining our forest lands.

Good drainage in agriculture means not only good drainage for individual farms, but also good storage capacity in the form of forest lands, for the surplus water which accumulates near the sources of large rivers.

39. The Sources of Heat in soils are (1) solar heat, and (2) heat resulting from chemical action. Solar heat is the main source for crop production. The action of heat upon soils has been studied extensively by Schübler. The amount of heat a soil is capable of absorbing depends upon its texture and moisture content. All dark-colored soils have a greater power for absorbing heat than light-colored ones. From Schübler's experiments it appears that when dry, there may be as great a difference as 8° C., between light- and dark-colored soils. When one set of soils was covered with a thin white coat of magnesia, and another set with lampblack, and exposed under like conditions, the temperatures were:[6]

	White coating.	Black coating.
Sand	43	50
Gypsum	43	51
Humus	42	49
Clay	41	48
Loam	42	50

The presence of water in the soil modifies the power for absorbing heat. A sandy soil for example retains about 12 per cent. of water, while a humus soil retains 35 per cent. The additional amount of water in the humus soil may cause the soil temperature to be lower than that of the sandy soil. While the humus soil absorbs more heat than the sandy soil, the heat is used up in evaporating water. A sandy soil readily warms up in the spring on account of the relatively small amount of water which it contains.

The specific heat of a soil is the amount of heat required to raise a given weight 1° C., as compared with the heat required to raise the same weight of water 1°. The specific heat of soils ranges from 0.2 to 0.4.

The effect of drainage upon soil temperature is marked. The surface of well-drained land is usually several degrees warmer than that of poorly drained land. Water being a poor conductor of heat it follows that soils which are saturated are slow to warm up in the spring. At a depth of 2 or 3 feet there is not such a marked difference in the temperature of wet and dry soils. It is to be observed that with proper systems of drainage the surplus water is removed from the surface soil and stored up in the subsoil for the future use of the crop, and at the same time the temperature of the surface soil is raised, thus improving the conditions for crop growth. The relation of drainage to the proper supply of water and temperature for crop growth is a matter which generally receives too little consideration in field practice.

40. Heat from Chemical Reactions within the Soil. — Heat also results from the slow oxidation of the organic matter of the soil. When organic matter decomposes, it produces heat. A load of manure, when it rots in the soil, gives off the same amount of heat as if it were burned. Manured land is usually 1° or 2° warmer in the spring than unmanured land; this is due to the oxidation of the manure. In an acre of rich prairie soil it has been estimated that the amount of organic matter which undergoes oxidation produces as much heat annually as would be produced from a ton of coal.[16] In well-drained and well-manured land, the additional heat is an important factor for stimulating crop growth, particularly in a cold, backward spring. The production of heat from manure is illustrated in the case of hotbeds where well-rotted manure is covered with soil; this results in raising the temperature of the soil. When soils are well manured, heat is retained more effectually. In the case of early frosts, crops on well-manured land will often escape.

41. Relation of Heat to Crop Growth.—All plant life is directly dependent upon solar heat as the source of energy for the production of plant tissue. The heat of the sun is the main force at the plant's disposal for decomposing water and carbon dioxide and for producing starch, cellulose, and other compounds. The growth of crops is the result of the transformation of solar heat into chemical energy which is stored up in the plant. When the plant is used for fuel or for food the quantity of heat produced by complete oxidation is equal to the amount of heat required for formation.

COLOR OF SOILS

42. Organic Matter and Iron Compounds.—The principal materials which impart color to soils are organic matter and iron compounds. Soils containing large amounts of organic matter are dark-colored. A union of the decaying organic matter and the mineral matter of the soil also produces compounds, brown or black in color. When moist, many soils are darker than when dry, and soils in which the organic matter has been kept up by the use of manures are darker than unmanured soils.[17] When rich, black, prairie soils lose their organic matter through improper methods of cultivation or when the organic matter (humus) is extracted in chemical analysis the soils become light-colored.

The red color of soils is imparted by ferric oxide, the yellow by smaller amounts of the same material. The greenish tinge is supposed to be due to the presence of ferrous compounds, such soils being so close in texture as to exclude the oxidizing action of the air. Black and yellow soils are, as a rule, the most productive. Color may serve, to a slight extent, as an index of fertility. The main reason why black soils are so generally fertile is because they contain a higher per cent. of nitrogen. Black soils are occasionally unproductive because of the presence of compounds injurious to vegetation.

43. Odor and Taste of Soils. — Soils containing liberal amounts of organic matter have characteristic odors. The odoriferous properties of a soil are due to the presence of aromatic bodies produced by the decomposition of organic matter. In cultivated soils these bodies have a neutral reaction. Poorly drained peaty soils give off volatile acid compounds when dried. The amount of aromatic compounds in soils is very small.

The taste of soils varies with the chemical composition. Poorly drained peaty soils usually have a slightly sour taste, due to the presence of organic acids. Alkaline soils have variable tastes according to the prevailing alkaline compound. The taste of a soil frequently reveals a fault, as acidity or alkalimetry.

44. Power of Soils to Absorb Gases. — All soils possess, to a variable extent, the physical power of absorbing gases. When decomposing animal or vegetable matter is mixed with the soil the gaseous products given off are absorbed. The absorption is both a chemical and a physical action. The chemical changes which occur, as the absorption of ammonia, are considered in the chapter on fixation. The organic matter of the soil is the principal agent in the physical absorption of gases; peat, for example, has the power of absorbing large amounts. This action is similar to that of a charcoal filter in removing noxious gases from water.

45. Relation of Soils to Electricity. — There is always a certain amount of electricity in both the soil and the air. The part which it takes in plant growth is not well understood. The action of a strong current upon the soil undoubtedly results in a change in chemical composition; a feeble current has either an indifferent or a slightly beneficial effect upon crop growth. In order to change the composition of the soil so as to render the unavailable plant food available, would require a current destructive to vegetation. When plants are subjected to too strong a current of electricity, they wilt and have all of the after-appearance of frost. The slightly beneficial action upon plant growth is not sufficient to warrant its use as yet in general crop production on account of cost. The action of a weak current of electricity upon plants is undoubtedly physiological rather than chemical, unless it be in the slightly favorable influence which it exerts upon nitrification. The resistance which soils, when wet, offer to electricity has been taken by Whitney as the basis for the determination of moisture in soils.[18]

46. Importance of the Physical Study of Soils. — From what has been said regarding the physical properties of soils it is evident that such a study will give much valuable information regarding their probable agricultural value. While the physical properties should always be taken into consideration, they should not form the sole basis for judging the character of a soil, because two soils from the same locality frequently have the same general physical composition and still have entirely different crop-producing powers, due to a difference in chemical composition.

Attempts have been made to overestimate the value of the physical properties of soils and to explain nearly all soil phenomena on the basis of soil physics. Important as are the physical properties of a soil, it cannot be said that they are of more importance than the chemical properties. In fact the four sciences, chemistry, physics, geology, and bacteriology, are all closely connected and each contributes its part to our knowledge of soils.

CHAPTER II

GEOLOGICAL FORMATION AND CLASSIFICATION OF SOILS

47. Geological Study of Soils. — The geological study of a soil concerns itself with the past history of that soil, the material out of which it has been produced, together with the agencies which have taken a part in its formation and distribution. Geologically, soils are classified according to the period in the earth's history when formed, and also according to the agencies which have distributed them. Agricultural geology is of itself a separate branch of agricultural science. The principles of soil formation and soil distribution should be understood, because they have such an important bearing upon soil fertility. In this work, only a few of the more important topics of agricultural geology are treated in a general way.

48. Formation of Soils. — Many geologists believe the surface of the earth to have been at one time solid rock. It is now almost universally held that soils have been formed from rock by various agents; as, (1) heat and cold, (2) water, (3) gases, (4) micro-organisms and vegetable life. The disintegration of rock is usually effected by the combined action of these various agents. The process of soil formation is a slow one and the various agents have been at work for an almost indefinite period.

49. Action of Heat and Cold. — The cooling of the earth's surface, followed by a contraction in volume, resulted in the formation of fissures which exposed a larger area to the action of other agents. The unequal cooling of the rock caused a partial separation of the different minerals, resulting in the formation of smaller rock particles from larger rock masses. This is well illustrated by the familiar splitting and crumbling of many stones when heated. The action of frost upon rock is also favorable to soil formation. The freezing of water in rock crevices results in breaking up the rock masses, forming smaller bodies. The force exerted by water when it freezes is sufficient to detach large rocks.

50. Action of Water. — Water acts upon soils both chemically and physically. In its physical action, water has been the most important agent that has taken a part in soil formation. The surface of rocks has been worn away by moving water and in many cases deep ravines and canons have been formed; the pulverized rock, being carried along by the water and deposited under favorable conditions, forms alluvial soil. This is illustrated in the workings of large rivers where the pulverized rock masses are deposited along the river and at its mouth. A large portion of the soil in valleys and river bottoms has been deposited by water. The action of water is not alone confined to the formation of soils along water courses, but is equally important in the formation of soils remote from streams or lakes, as in the case of soils deposited by glaciers.

51. Glacial Action.—At one time in the earth's history, the ice-fields of polar regions covered much larger areas than at present.[19] Changes of climate caused a recession of the ice-fields, and resulted in the movement of large bodies of ice, carrying along rocks and frozen soil. The movement and pressure of the ice pulverized the rock and produced soil. This action is well illustrated at the present time where mountains rise above the snow line, and the ice and snow melting at the base are replaced by ice and snow from above moving down the side of the mountain. When the glacier receded, stranded ice masses were distributed over the land. These melted slowly and by their grinding action hollowed out places which finally became lakes. The numerous lakes at the source of the Mississippi River and in central Minnesota are supposed to have been formed by glacial action. The terminal of a glacier is called a moraine and is covered with large boulders which have not been disintegrated. The course of a glacier is frequently traced by the markings or scratches of the mass on rock ledges. In glacial soils, the rocks are never angular, but are smooth because of the grinding action during transportation. The area of glacial soils in the northern portion of the United States is quite large. These soils are, as a rule, fertile because of the pulverization and mixing of a great variety of rock.

52. Chemical Action of Water. — The chemical action of water has not taken such an important part in soil formation as the physical action. While nearly all rocks are practically insoluble in water there is always some material dissolved, evidenced by the fact that all spring-water contains dissolved mineral matter. When charged with carbon dioxide and other gases, water acts as a solvent upon rocks. It converts many oxides, as ferrous oxide, into hydroxides. The chemical action of water may result in the formation of new compounds more soluble or readily disintegrated, as deposits of clay, which have been produced by the chemical and physical action of water upon feldspar rock. Limestone is quite readily disintegrated by water, which produces many chemical changes in both rocks and soils. The chemical action of fertilizers known as fixation can take place only in the presence of water. In fact water is necessary for nearly all chemical reactions in the soil.

53. Action of Air and Gases. — The part which air has taken in soil formation has not been as prominent as that taken by water. By the aid of oxygen, carbon dioxide, and other gases and vapors in the air, rock disintegration is hastened. The action of oxygen changes the lower oxides to higher forms. All rock contains more or less oxygen in chemical combination.

The carbon dioxide of the air under some conditions favors the formation of carbonates. The disintegrating action of air, moisture, and frost is illustrated in the case of building stones which in time crumble and form a powder. The combined action of air, moisture, and frost is called weathering.

54. **Action of Vegetation.** — Some of the lower forms of plants as lichens do not require soil for growth, but are capable of living on the bare surface of rocks, obtaining food from the air, and leaving a certain amount of vegetable matter which undergoes decay and is incorporated with the rock particles, preparing the way for higher orders of plants which take their food from the soil. When this vegetable matter decays it enters into chemical combination with the pulverized rock, forming humates.[17] The disintegrating action of plant roots and vegetable matter upon rocks has been an important factor in soil formation.

55. **Action of Micro-organisms.** — Micro-organisms, found on the surface and in the crevices of rocks, are considered by many as active agents in bringing about rock decay. The nitrifying organisms have taken an important part in rendering soils fertile, and these with others have without doubt aided in soil formation. Some of the organisms found on the surface of rocks are capable of producing carbonaceous matter out of the carbon dioxide and other compounds of

the air.[20] This action results in adding vegetable matter to the soil.

56. Combined Action of the Various Agents. — In the decay of rocks the various agents named,—water acting mechanically and chemically, heat and cold, air, and vegetation,—have been acting jointly, and have produced a more rapid disintegration than if each agent were acting separately. One of the best evidences that soil is derived from rock is that there are frequently found in fields pieces of rock which are actually rotten, and, when crushed, closely resemble the prevailing soil of the field. This is particularly true of clay soils where fragments of disintegrated feldspar are found which, when crushed, resemble the soil in which the feldspar was imbedded.

DISTRIBUTION OF SOILS

57. Sedentary and Transported Soils. — The place where a soil is found is not necessarily the place where it was produced ; that is, a soil may be produced in one locality and transported to another. Soils are either sedentary or transported. Sedentary soils are those which occupy the original position where they were formed. They usually have but little depth before rock surface is reached. The stones in such soils have sharp angles because they have not been ground by transportation. Transported soils are those which have been formed in one locality and carried by various agents as glaciers and rivers, to other localities, the angles of stones in these soils being ground off during transportation. Transported soils are divided into classes according to the ways in which they have been formed ; as, drift soils produced by glaciers, and alluvial soils formed by rivers and deposited by lakes.

Other agents which have taken a part in soil transportation are wind and volcanic action. Many soils have been either formed or modified by the wind. The denuding action of heavy wind storms upon many prairie soils is well known. Soil particles are carried long distances and then deposited, forming wind-drifted soils. In some localities volcanic soils are found; they are extremely varied in texture and composition—some are very fertile and contain liberal amounts of alkaline salts and phosphates, while others contain so little plant food that they are sterile.

ROCKS AND MINERALS FROM WHICH SOILS ARE FORMED

58. Composition of Rock. — Rocks are composed of either a single mineral or of a combination of minerals. Most of the common minerals have a variable range of composition, due to the fact that one element or compound may be partially or entirely replaced by another. Most of the common rocks from which soils have been produced are composed of feldspar, mica, hornblende, and quartz.

59. Quartz and Feldspar. — Quartz is the principal constituent of many rock formations. Pure quartz is silicic anhydride (SiO_2). White sand is nearly pure quartz. A soil formed from pure quartz would be sterile. Feldspar is composed of silica, alumina, and potash or soda. Lime may also be present, and replace a part or nearly all of the soda. If the mineral contains soda as the alkaline constituent it is known as albite, or if mainly potash it is called potash feldspar or orthoclase.

The members of the feldspar group are insoluble in acids and before disintegration takes place are not capable of supplying plant food. Potash feldspar contains from 12 to 15 per cent. of potash, none of which is of value as plant food. When feldspar undergoes disintegration it produces clay. A soil formed from feldspar is usually well stocked with potash.

Orthoclase,	$AlKSi_3O_8$..............	Potash Feldspar.
Albite,	$AlNaSi_3O_8$..............	Sodium Feldspar.

60. Hornblende.—The hornblende and augite groups are formed by the union of magnesium, calcium, iron, and manganese, with silica. There are none of the members of the alkali family in hornblende. The augites are double silicates of iron, manganese, calcium, and magnesium. Quite frequently phosphoric acid is present in chemical combination with the iron. The members of this group are readily distinguished by their color which is black, brown, or brownish green. The hornblendes are insoluble in acids, hence unavailable as plant food, and when disintegrated do not as a rule form very fertile soils.

61. Mica. — Mica is quite complex in composition, is an abundant mineral, and is composed of silica, iron, alumina, manganese, calcium, magnesium, and potassium. Mica is a polysilicate. The color may be white, brown, black, or bluish green owing to the absence of iron, or to its presence in various amounts. The chief physical characteristic of the members of this group is the ease with which they are split into thin layers. It is to be observed that the mica group contains all of the elements of both feldspar and hornblende.

Soils formed from the disintegration of mica are usually fertile owing to the variety of essential elements present. Frequently small pieces of undecomposed mica are found in soils.

62. Zeolites. — The zeolites form a large group of secondary minerals. They are polysilicates containing alumina and members of the alkali and lime families, and all contain water held in chemical combination. They are soluble in dilute hydrochloric acid and belong to the group of compounds which are capable, to a certain extent, of serving as plant food. In color they are white, gray, or red. Zeolites are quite abundant in clay and are an important factor in soil fertility. It is this group which takes such an important part in the process of fixation. The zeolites, when disintegrated, particularly by glacial action, form very fertile soils.

63. **Granite** is composed of quartz, feldspar, and mica. It is a very hard rock and is slow to disintegrate. The different shades of granite depend upon the proportion in which the various minerals are present. Inasmuch as granite contains so many minerals it usually follows that thoroughly disintegrated granite soil is very fertile. Pure powdered granite before undergoing disintegration furnishes no plant food. After weathering, the plant food gradually becomes available. Gneiss belongs to the granite series but differs from true granite by containing a larger amount of mica. Mica schist contains a larger amount of mica than gneiss.

64. **Apatite or Phosphate Rock.** — Apatite is composed mainly of phosphate of lime, $Ca_3(PO_4)_2$, together with small amounts of other compounds as fluorides and chlorides. This mineral is generally of a green or yellow color. It is present in many soils and is of little value as plant food unless associated with organic matter or some soluble salts.

65. **Kaolin** is chemically pure clay and is formed by the disintegration of feldspar. When feldspar is decomposed and is acted upon by water the potash is removed and water of hydration is taken up, forming the product kaolin, which is hydrated silicate of alumina, $Al_4(SiO_4)_3.H_2O$. Impure varieties of clay are col-

ored red and yellow on account of the presence of iron and other impurities. Pure kaolin is white, is insoluble in acids, and is incapable of supplying any nourishment to plants. Clay soils are fertile on account of the other minerals and organic matter mixed with the clay and are usually well stocked with potash because of the incomplete removal of the potash from the disintegrated feldspar. It is to be observed that the term clay used chemically means aluminum silicate, while physically it is any substance, the particles of which are less than 0.005 mm. in diameter.

66. Other Rocks and Minerals. — In addition to the rocks and minerals which have been discussed, there are many others that contribute to soil formation, as limestone, which is calcium carbonate; dolomite, a double carbonate of calcium and magnesium; serpentine, a silicate of magnesium; and gypsum, calcium sulphate.

CHEMICAL COMPOSITION OF ROCKS [10]

	Silica, SiO_2.	Alumina, Al_2O_3.	Potash, K_2O.	Soda, Na_2O.	Lime, CaO.	Magnesia, MgO.	Ferric oxide, Fe_2O_3.	Water, H_2O.
Quartz	95–100	....	....	....	....	...	....	....
Feldspar	55–67	20–29	0–12	1–10	1–11	....	....	....
Kaolin	46	39	....	....	....	....	....	14
Apatite	....	....	....	....	53	....	(P_2O_5 42)	....
Mica	40–45	12–37	5–12	....	....	....	....	1–5
Hornblende	40–55	0–15	....	....	....	....	....	....
Granite	60–80	10–15	4–5	....	....	....	2–3	....

CHAPTER III

THE CHEMICAL COMPOSITION OF SOILS

67. Elements Present in Soils. — Physically considered, a soil is composed of disintegrated rock mixed with animal and vegetable matter; chemically considered, the rock particles are composed of a large number of simple and complex compounds, each compound in turn being composed of elements chemically united. Elements unite to form compounds, compounds to form minerals, minerals to form rocks, and disintegrated rocks form soil. When rocks decompose, the disintegration, except in a few cases, is never carried to the extent of liberating the elements, but the process ceases when the minerals have been broken up into compounds. While there are present in the crust of the earth between 65 and 70 elements, only about 15 are found in animal and plant bodies, and of these but 12 are absolutely essential. Only four of the elements which are of most importance are at all liable to be deficient in soils. These four elements are: nitrogen, phosphorus, potassium, and calcium.

68. Classification of the Elements. — The elements found most abundantly in soils are divided into two classes:

Acid-forming elements		Base-forming elements	
Oxygen	O	Aluminum	Al
Silicon	Si	Potassium	K
Phosphorus	P	Sodium	Na
Sulphur	S	Calcium	Ca
Chlorine	Cl	Magnesium	Mg
Nitrogen	N	Iron	Fe
Hydrogen	H		

Boron, fluorine, manganese, and barium are usually present in small amounts, besides others which may be present in traces, as the rare elements lithium and titanium.

For crop purposes the elements of the soil may be divided into three classes:

1. Essential elements most liable to be deficient: nitrogen, potassium, phosphorus, and calcium.

2. Essential elements usually abundant: iron, magnesium, and sulphur.

3. Unnecessary and accidental elements, usually abundant, as chlorine, silicon, aluminum, and manganese.

69. Combination of Elements.—In dealing with the composition of soils the percentage amounts of the individual elements are not given, except in the case of nitrogen; but instead, the percentage amounts of the various oxides. This is because the elements do not exist as free elements in the soil, but are combined with oxygen and other elements to form compounds. When considered as oxides the acid- and base-forming elements may form various compounds as:

Calcium	Silicate Phosphate Chloride Sulphate Carbonate
Potassium . Sodium ... Magnesium Iron	

The following reactions will explain some of the more elementary forms of combinations:

$CaO + SiO_2 = CaSiO_3$	$CaO + SO_3 = CaSO_4$
$3CaO + P_2O_5 = Ca_3(PO_4)_2$	$K_2O + SO_3 = K_2SO_4$
$CaO + SO_3 = CaSO_4$	$Na_2O + SO_3 = Na_2SO_4$
$CaO + CO_2 = CaCO_3$	$MgO + SO_3 = MgSO_4$

When considered as the oxide, calcium may combine with any of the oxides of the acid-forming elements, as indicated by the reactions, to form salts. Each of the compounds formed from the more common elements may have a separate value as plant food, hence it is important to consider the combinations of each element separately.

ACID-FORMING ELEMENTS

70. Silicon.—The element silicon makes up from a quarter to a third of the solid crust of the earth and next to oxygen is the most abundant element found in the soil. Silicon never occurs in the soil in the free state. It either combines with oxygen to form silica (SiO_2), or with oxygen and some base-forming element or elements to form silicates. Silica and the various silicates are by far the most abundant compounds present in the soil. Silicon is not one of the elements absolutely necessary for plant growth, and even if it were, all soils are so abundantly supplied that it would not be necessary to use it in fertilizers.

71. **Double Silicates.** — When two or more base-forming elements are united with the silicate radical, a double silicate is formed. In fact the double silicates are the most common forms present in soils. There are also a number of forms of silicic acid which greatly increase the number of silicates, and a study of the composition of soils is largely a study of these various silicates.

72. **Carbon** is an acid-forming element and belongs to the same family as silicon; it is found in the soil as one of the main constituents of the volatile or organic compounds. Carbon also unites with oxygen and the base-forming elements, producing carbonates, as calcium carbonate or limestone. The carbon of the soil takes no direct part in forming the carbon compounds of the plant. It is not necessary to apply carbon fertilizers to produce the carbon compounds of plants because the carbon dioxide of the air is the source for crop production. It is estimated that there are 30 tons of carbon dioxide in the air over every acre of the earth's surface.[21] The carbon in the soil is an indirect element of fertility, because it is usually combined with elements, as nitrogen and phosphorus, which are absolutely necessary for crop growth.

73. Sulphur occurs in all soils mainly in the form of sulphates, as calcium sulphate, magnesium sulphate, and sodium sulphate. It is an important element of plant food. There is generally less than one-half per cent. of sulphuric anhydride in ordinary soils, but the amount required by crops is small and there is usually an abundance in all soils.

74. Chlorine is present in all soils, generally in combination with sodium, as sodium chloride. It may be in combination with other bases. Soils which contain more than 0.10 per cent. are, as a rule, sterile. Chlorine is present in the soil in soluble forms. It occurs in all plants, although it is not absolutely necessary for plant growth, hence its combination in fertilizers is unnecessary. Chlorine with sodium, as common salt, is sometimes used as an indirect fertilizer.

75. Phosphorus, one of the essential elements for plant growth, is combined with both the volatile and non-volatile elements of the soil. Plants cannot make use of it in other forms than those of phosphates. Phosphorus is usually present in the soil as calcium phosphate, magnesium phosphate, or aluminum phosphate, and may also be combined with the humus, forming humic phosphates. The form in which the phosphates are present, as available or unavailable, is an important factor in soil fertility. Soils are quite liable to be deficient in phosphates, inasmuch as they are so largely drawn upon by many crops, particularly grain crops where the phosphates accumulate in the seed, and are sold from the farm.

76. Nitrogen. — This element is present in soils in various forms. As a mineral constituent it is combined with oxygen and the base-forming elements as potassium, sodium, or calcium, forming nitrates and nitrites, which, on account of their solubility, are never found in ordinary soils in large amounts. Nitrogen is present mainly in organic combinations, being associated with carbon, hydrogen, and oxygen as one of the elements forming the organic matter of soils. Nitrogen may also be present in small amounts in the form of ammonia, or of ammonium salts, derived from rain water and from the decay of vegetable and animal matter. While nitrogen is present in the air, in a free state, in large amounts, it can be appropriated indirectly as food in this form by only a limited number of plants. For ordinary agricultural crops, particularly the cereals, nitrogen must be supplied through the soil as combined nitrogen. This element is the most expensive and is liable to be the most deficient of any of the elements of plant food. No other element takes such an important part in agriculture or in life processes.

77. Oxygen. — Oxygen is combined with both the acid- and base-forming elements and is present in nearly all of the compounds of the soil. It has been estimated that about one-half of the crust of the earth is composed of oxygen, which is found in large proportions combined with silicon, forming silica. That which is held in chemical combination in the soil takes no part in the formation of plant tissue. In addition to being present in the soil, oxygen constitutes eight-ninths of the weight of water and about one-fifth of the weight of air. It also forms about 50 per cent. of the compounds found in plants and animals. Oxygen in the interstices of the soil is an active agent in bringing about many chemical changes, as oxidation of the organic matter, and disintegration of the soil particles.

78. Hydrogen. — This element is never found in a free state in the soil, but is combined with carbon and oxygen as in animal and vegetable matter, with oxygen to form water, and in a few cases with some of the base elements to form hydroxides. It is not found in large amounts in the soil, and that which forms a part of the tissues of plants and animals comes from the hydrogen in water. Hydrogen in the organic matter of soils takes no part directly in producing the hydrogen compounds of plants. On account of its lightness, hydrogen never makes up a very large proportion, by weight, of the composition of bodies.

BASE-FORMING ELEMENTS

79. Aluminum is present in the soil in the largest quantity of any of the base elements. It is calculated that from 6 to 10 per cent. of the solid crust of the earth is aluminum. As previously stated it is one of the constituents of clay, and furnishes nothing for plant growth. Physically, however, the aluminum compounds take an important part in soil fertility. Aluminum is usually in combination with silica or with silica and some base-forming element, as iron, potassium, or sodium. The various forms of aluminum silicates are the most numerous compounds present in soils.

80. **Potassium** is present in the soil mainly in the form of silicates, and is one of the elements absolutely necessary for plant growth. The term potash (potassium oxide, K_2O) is usually employed when the potassium compounds are referred to. The amount and form of the soil potash have an important bearing upon fertility. Potassium is one of the three elements of plant food usually supplied in fertilizers. The form in which it is present in the soil and its economic supply as plant food, are important factors of crop growth, and are considered in detail in Chapter VIII. The amount of potash in soils ranges from 0.02 to 0.8 per cent. In a fertile soil it rarely falls below 0.2 per cent.

81. **Calcium** is present in the soil in a variety of forms, as calcium carbonate, calcium silicate, and calcium phosphate. The calcium oxide (CaO) of the soil is generally spoken of as the lime content. Calcium carbonate and sulphate are important factors in imparting fertility. A subsoil with a good supply

of lime will stand heavy cropping and remain in excellent chemical and physical condition for crop growth. In a good soil there is usually 0.2 of a per cent. or more of lime mainly as calcium carbonate.

82. **Magnesium** is present in all soils and is usually associated with calcium, forming the mineral dolomite, which is a double carbonate of calcium and magnesium. Magnesium may also be present in the soil in the form of magnesium sulphate or magnesium chloride. All crops require a certain amount of magnesia in some form, in order to reach maturity and produce fertile seeds. There is generally in all soils an amount sufficient for crop purposes, hence it is not necessary to consider this element in connection with soil fertility.

83. **Sodium** is found in the soil mainly as sodium silicate, and is present to about the same extent as potassium which it resembles chemically in many ways; it cannot, however, replace the element potassium. Inasmuch as sodium takes such an indifferent part in plant nutrition it is never used as a fertilizer except in an indirect way.

84. **Iron** is an element necessary for plant food and is found in all soils to the extent of from 1 to 4 per cent. Crops require only a small amount of iron, hence there is always sufficient for crop purposes. Iron is present in soils in the form of oxides, hydroxides, and silicates.

85. Three Classes of Compounds. — For agricultural purposes, compounds present in soils may be divided into three classes:[16] The first class includes silicates and other compounds of potash, soda, lime, magnesia, phosphorus, etc., which are soluble in the soil-water and in dilute organic acids. This class

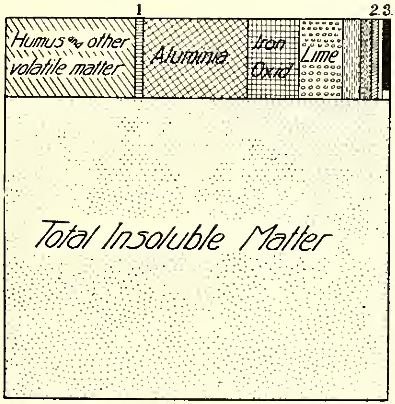


Fig. 17. Average composition of soils.
1. Nitrogen; 2. Potash; 3. Phosphoric acid.

represents the most soluble and the most active and valuable forms of plant food. There is only a very small amount in these forms. In 100 pounds of soil, rarely more than a few hundredths of a pound of any one of the important elements is soluble in the soil-water or in dilute organic acids.

The plant food of the second class is in a somewhat more insoluble form, and consists of all those compounds and silicates which are soluble in hydrochloric acid of twenty-three per cent. strength, 1.115 sp. gr. This class of compounds represents the limit of the solvent action of the stronger solutions of organic acids, such as are found in the roots of plants.

The third class of silicates includes all of those compounds which require the combined action of the highest heat and the strongest chemicals and fluxes in order to decompose them.

The first and second classes of silicates and other compounds are the only ones which possess any value as plant food. The third class, after undergoing the combined action of the various disintegrating agencies of nature, may be changed into the second class, called the zeolitic silicates. In this second class are also included all of the mineral elements combined with the humus. As a rule, not over fifteen or twenty per cent. of the total soil is in forms soluble in hydrochloric acid; and of the more important elements only one to six per cent. form a part of this fifteen. In two hundred samples of soil, the potash, nitrogen, lime, magnesia, phosphoric and sulphuric acids, amounted to 3.5 per cent. (Fig. 17). In many fertile soils the sum of the nitrogen, phosphoric acid, potash, lime, magnesia, and sulphuric and carbonic anhydrides is less than 1.50 per cent. This means that in every 100 pounds of soil there are only from 1.5 to 3.5 pounds of matter which can take any active part in the support of a crop, and 96 to 98.5 pounds are present simply as so much inert material.

86. Acid-insoluble Matter of Soils. — The insoluble residue obtained after digesting a soil with strong hydrochloric acid, contains potash, soda, and limited amounts of magnesia, and phosphoric acid, with other elements which are of no value as plant food. If a seed were planted in soil extracted with strong hydrochloric acid, it would make no growth after the reserve food in the seed had been exhausted. A plant grown in such a soil is shown in the illustration (Fig. 18).

Fig. 18. Oat plant grown in soil extracted with hydrochloric acid.

On the other hand it cannot be said that all of the plant food soluble in hydrochloric acid is equally valuable. In fact, the acid represents more than the limit of the crop's feeding power, when there is not enough of more soluble forms to aid in the first stages of growth.

In the following table the percentage amounts of compounds soluble and insoluble in hydrochloric acid are given:[16]

	Wheat soil.		Heavy clay soil.		Grass and grain soil.	
	Soluble in HCl	Insoluble residue	Soluble in HCl	Insoluble residue	Soluble in HCl	Insoluble residue
Insoluble matter	63.07	....	84.77	....	84.08	....
Potash	0.54	2.18	0.21	3.46	0.30	1.45
Soda	0.45	3.55	0.22	2.95	0.25	0.25
Lime	2.44	0.36	0.48	0.16	0.51	0.35
Magnesia	1.85	0.25	0.34	0.47	0.26	0.46
Iron	4.18	0.78	3.76	0.72	2.56	1.07
Alumina	7.89	5.54	6.26	5.44	2.99	9.72
Phosphoric acid	0.38	....	0.12	0.08	0.23	0.05
Sulphuric acid	0.11	0.24	0.09	0.25	0.08	0.02

The insoluble matter after digestion with hydrochloric acid, was submitted to fusion analysis, and the figures given under insoluble residue represent the amounts of potash, soda, etc., insoluble in acids. In the clay soil 96 per cent. of the total potash is in forms insoluble in hydrochloric acid.

87. Soluble and Insoluble Potash and Phosphoric Acid.— From the preceding table it is to be observed that the larger portion of the potash in the soil is insoluble in hydrochloric acid. A soil may contain from 2 to 3 per cent. of total potash, and 90 per cent. or more may be in such firm chemical combination with aluminum, silicon, and other elements, as to resist the solvent action of plant roots. The larger portion of the phosphoric acid of the soil is soluble in hydrochloric acid. In some soils, however, from 20 to 40 per cent. is present in the third class of compounds. When a soil is digested with hydrochloric acid, the insoluble residue is usually a fine gray powder. Some clay soils retain their red color even after treatment with acids showing that the iron is in part in chemical combination with the more complex silicates.

In order to decompose the insoluble residue obtained from the treatment with hydrochloric acid, fluxes, as sodium carbonate and calcium carbonate, are employed which act upon the complex silicates at a high temperature, and produce silicates soluble in acids. Plants, however, are unable to obtain food in such complex forms of chemical combination.

88. How a Soil Analysis is Made. — A sample is obtained from a field by taking several small samples to a depth of 6 to 9 inches, from different places, and uniting them to form one sample. All coarse stones and roots are removed and a record is made of the amount of these materials. The soil is air dried, the hard lumps are crushed, and the materials passed through a sieve with holes 0.5 mm. in diameter. Only the fine earth is used for the chemical analysis. Ten grams of soil are weighed into a soil digestion flask, and 10 cc. hydrochloric acid of 1.115 sp. gr. are added for every gram of soil used. The digestion flask is provided with a glass stopper which is connected with a condensing tube. The soil digestion flask is then placed in a hot water-bath and the digestion is carried on for twelve hours at the temperature of boiling water. After the digestion is completed the contents of the flask are transferred to a filter and separated into an insoluble part, and the acid solution which contains the compounds of the various elements. The following table will give a general idea of how the different materials are obtained from the acid solution. This table is not intended as an outline for soil analysis, but simply to give the student of general chemistry an idea of how an analysis is made.

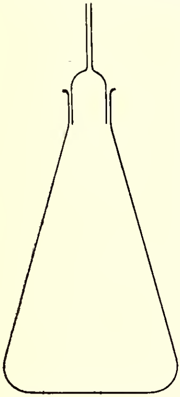


Fig. 19. Digestion flask.

The second half of the acid solution is divided into three portions. The first portion is used for the determination of phosphoric acid. The acid is precipitated with ammonium molybdate. The second portion is used for determination of sulphuric acid, which is precipitated as barium sulphate. The carbon dioxide is determined on a fresh portion of the original soil; the acid is liberated with hydrochloric acid and the carbon dioxide is retained by absorbents and weighed. The nitrogen and humus are determined in separate portions of the original soil.

Analysis of Soil.

Soil digested with hydrochloric acid and filtered, an insoluble residue and an acid solution are obtained. One-half of filtrate is used as noted below.

<table>
<tr><td rowspan="4">Residue. — Either dried, ignited, and weighed, or analyzed by fusion process.</td><td colspan="4">Filtrate, after removing soluble silica, is rendered alkaline with ammonia and a precipitate obtained.</td></tr>
<tr><td rowspan="3">Precipitate contains : Iron, alumina and phosphoric acid. Precipitate ignited and weighed. Dissolved in sulphuric acid and iron determined. The phosphoric acid is determined from a separate portion of the original solution. Sum of iron and phosphoric acid subtracted from total gives alumina.</td><td colspan="3">Filtrate. — Ammonium oxalate is added and a precipitate is obtained.</td></tr>
<tr><td rowspan="2">Precipitate is calcium oxalate.</td><td colspan="2">Filtrate.—Divide into two parts.</td></tr>
<tr><td>To one part sodium phosphate and ammonia are added. Precipitate obtained is ammonium magnesium phosphate.</td><td>Potash and soda are determined after all other materials are removed.</td></tr>
</table>

89. Value of Soil Analysis. — Opinions differ as to the value of soil analysis. It is claimed by some that a chemical analysis of a soil is of no practical value because it fails to give the amount of available plant food. A soil may have, for example, 0.4 per cent. of potash soluble in hydrochloric acid and still not contain sufficient available potash to produce a good crop, while another soil may contain 0.2 per cent. of potash soluble in hydrochloric acid and produce good crops. While these facts are frequently true, it does not necessarily follow that the chemical analysis of a soil is of no value because other solvents than hydrochloric acid may be used for soil analysis. Hydrochloric acid is used because it represents the limit of the solvent power of plants. The figures obtained by the use of hydrochloric acid are valuable inasmuch as they indicate whenever an element is present in amounts which are too limited to admit of crop production. Suppose an ordinary soil contains 0.05 per cent. of acid-soluble potash, this would be too small an amount to produce good crops. The soil might contain 0.5 per cent. and yet not have a sufficient amount of available potash. Hence it is, that in interpreting results, the hydrochloric acid solvent may show when a soil is wholly deficient in any one element, as is sometimes the case, but it does not necessarily show a deficiency in the case of a soil rich in acid-soluble potash; this can, however, be approximately indicated, by the use of other solvents, as explained in section 90.

The character of the soil, as acid, alkaline, or neutral should first be determined, because plant food exists in a different form in each class of soils. If a soil contains from 0.3 to 0.5 per cent. or more of lime (as CaO) and from 0.1 to 0.4 per cent. of carbon dioxide (CO_2), and is not strongly alkaline, there is a reasonable content of lime carbonate. If, however, the soil contains only 0.01 or 0.02 per cent. of carbon dioxide, then the lime is not present as carbonate, but is probably present as a silicate, in which case the soil may stand in need of a lime fertilizer. A soil which gives an alkaline or neutral reaction and contains 0.15 per cent. of phosphorus pentoxide, and is well supplied with organic matter and lime, is amply provided with phosphoric acid, and under such conditions the extensive use of phosphate fertilizers is not required, except possibly for special crops. Hilgard states that should the per cent. of phosphoric acid be as low as 0.05, there is, in all probability, a poverty of this element.

Soils containing less than 0.07 per cent. of total nitrogen are usually deficient. A soil containing as high as 0.15 or 0.2 per cent. of nitrogen may fail to respond to crop production. Such cases are generally due to some abnormal condition of the soil, as a lack of alkaline compounds which are necessary for nitrification. The appearance of the crop is the best indication as to a deficiency of nitrogen.

A soil which contains less than 0.15 per cent. of potash soluble in hydrochloric acid is quite apt to be deficient. Soils which contain 0.5 per cent. or more of lime carbonate will produce good crops on a smaller working supply of potash than soils which are poverty-stricken in lime. As a rule the best agricultural soils contain from 0.3 to 0.6 per cent. of potash. Sandy soils of good depth may contain less plant food than the figures given, and not be in need of fertilizers.

The term volatile matter is sometimes confused with the term organic matter. The volatile matter includes the organic matter and the water which is held in chemical combination as in the hydrated silicates. A soil may have a high per cent. of volatile matter and contain very little organic matter. Indeed all clays contain from 5 to 9 per cent. of water of hydration. The per cent. of humus, as will be explained in the next chapter, does not represent all of the organic matter.

The best results are obtained from soil analyses when an extended study is made of the soils of a locality. Then an unknown soil of that locality can be compared with a productive soil of known composition. An isolated soil analysis, like an isolated analysis of well water, frequently fails in its object because of a lack of proper normal standards for comparison.

When extended series of soil analyses have been made, much valuable information has been obtained.

Suppose a soil contains 0.40 per cent. of acid-soluble potash and field experiments indicate that there is a deficiency of available potash. This may be due to some abnormal condition of the soil, as an insufficient amount of other alkaline compounds as calcium carbonate to take the place of the potash which has been withdrawn by the crop, in which case the deficiency of potash could be remedied without purchasing soluble potash fertilizer, to become insoluble by fixation processes. If a soil contains only 0.04 per cent. of acid-soluble potash, the purchasing of potash fertilizers would be more necessary, but with 0.40 per cent. of acid-soluble potash the way is open to render this potash available for crops. The various ways of rendering acid-insoluble potash and other compounds available for crop production, as by rotation of crops, use of farm manures, use of lime and green manures, or by different methods of cultivation have not been sufficiently studied as yet to offer a solution to all of the problems of how to render inert plant food available.

90. Action of Organic Acids upon Soils. — Dilute organic acids, as a one per cent. solution of citric acid, have been proposed as solvents for the determination of easily available plant food. It has been shown in the case of the Rothamsted soils which have produced

50 crops of grain without manures, and which are markedly deficient in available phosphoric acid, that a 1 per cent. solution of citric acid dissolved only 0.003 per cent. of phosphoric acid while the soil contained a total of 0.12 per cent. In the case of an adjoining plot which had received phosphate manures until the soil contained a sufficient amount of available phosphoric acid to produce good crops, there was present 0.03 per cent. of phosphoric acid soluble in a 1 per cent. citric acid solution.[22]

Dilute organic acids are, to a certain extent, capable of showing deficiency of plant food. A soil which shows 0.03 per cent. of potash or phosphoric acid soluble in 1 per cent. citric acid is, as a rule, well stocked with available phosphoric acid. Prairie soils of high fertility yield from 0.03 to 0.05 per cent. of both potash and phosphoric acid soluble in dilute organic acids; soils which are deficient in these elements usually contain less than 0.01 per cent.

The action of a single organic acid of specific strength cannot be taken as the measure of fertility for all soils and crops alike, because different plants do not have the same amount or kind of organic acid in the sap. Of the various organic acids, citric possesses the greatest solvent action upon lime, magnesia, and phosphoric acid, while oxalic acid has the strongest solvent action upon the silicates. Tartaric acid appears to be less active as a solvent than either citric or oxalic acid. The combined use of dilute organic acids, as citric with hydrochloric acid of 1.115 sp. gr., will generally give an accurate idea of the character of a soil. A fifth-normal solution of hydrochloric acid has also been proposed as a measure of the soil's active phosphoric acid, and has given satisfactory results.[23]

The use of dilute organic acids renders it possible to detect small amounts of readily soluble phosphoric acid and potash. It has been stated that when a soil has been manured a few years with a phosphate fertilizer and brought into good condition as to available phosphoric acid, that a chemical analysis will fail to detect any difference in the soil before or after the treatment with fertilizer. In the case of hydrochloric acid as a solvent, this is true because an acre of soil to the depth of one foot weighs about 3,500,000 lbs. and 500 lbs. of phosphoric acid would increase the total amount of phosphoric acid about 0.015 per cent. When a dilute organic acid is used, only the more easily soluble phosphoric acid is dissolved, and this readily allows fertilized and unfertilized soils to be distinguished. The use of dilute organic acids and salts have shown a decided difference between soils fertilized and unfertilized with potash.[24]

91. Distribution of Plant Food. — In studying the chemical composition of a soil, the surface soil and the subsoil both require consideration. It frequently happens that the surface soil and the subsoil have entirely different chemical, as well as physical, properties. This is particularly true of the western prairie soils, where the surface soils generally contain less potash and lime, but more nitrogen and phosphoric acid, than the subsoils. When jointly considered the surface and subsoil have strong crop-producing powers, but if considered separately each would have weak points.

Since crops appropriate their food mainly from the silt and clay particles, the amount of plant food present in these grades of particles determines largely the reserve fertility of the soil. A soil in which 70 per cent. of the total potash is present in the silt and clay, is in better condition for crop production than a similar soil with a like amount of potash which is present mainly in the sand. Because a soil has a given composition, it does not follow that all of the different grades of particles have the same composition. In fact the different grades of soil particles may have as varied a composition as is met with among different soils.[25]

COMPOSITION.

	Composition of soil. Per cent.	Composition of particles.							
		0.5 mm. diameter. 13.67 per cent.		0.25 mm. diameter. 12.54 per cent.		0 25 mm. diameter. 23.56 per cent.		Clay. 21.64 per cent.	
		1.	2.	1.	2.	1.	2.	1.	2.
Insoluble matter.	82.83	96.48	15.75	92.23	13.95	83.12	23.76	49.06	13.91
Potash	0.63	0.12	1.60	0.29	6.35	0.53	19.05	1.47	50.80
Soda............	0.09	0.21	...	0.28	...	0.24	...	...	...
Lime	0.27	0.09	3.70	0.18	8.10	0.13	11.11	0.09	11.11
Magnesia	0.45	0.10	2.22	0.26	6.66	0.46	24.44	1.33	64.44
Ferric oxide.....	5.11	1.03	2.74	2.34	5.67	4.76	21.72	18.76	79.45
Alumina	8.09	1.21	2.10	2.64	4.07	4.32	12.85	18.19	49.01
Phosphoric acid .	0.21	0.02	...	0.03	...	0.11	9.52	0.18	19.01
Sulphuric acid...	0.02	0.03	...	0.03	...	0.02	50.00	0.06	50.00
Volatile matter ..	3.14	0.92	9.23	1.72	7.32	5.61	45.50	9.00	42.30

The figures under 1 give the composition of the particles, while under 2 are given the results calculated on the basis of the total amount of each element. For example, the clay contains 1.47 per cent. of potash, while 50.8 per cent. of the total potash of the soil is in the clay particles.

A soil may contain a comparatively low per cent. of potash or phosphoric acid, mainly in the finer particles and evenly distributed so that the crop is better supplied with food than if more were present in the larger particles, unevenly distributed. The distribution of the plant food in the soil has not been so extensively studied as the question of total plant food. Sometimes in judging the character of a soil from a chemical analysis, a soil fault, as lack of potash in the surface soil, is corrected by a high per cent. of the same element in the subsoil. The distribution of plant food in both surface soil and subsoil, as well as in the various grades of soil particles, is an important factor of fertility.

92. Composition of Typical Soils.—A few examples are given, in tabular form, of the chemical composition of soils from different regions in the United States. On account of variations in the same localities, the figures represent the composition of only limited areas of soils. There have been made in the United States a large number of soil analyses, which as yet have not been compiled nor studied in a systematic way.

Composition of Typical Soils.[16]

	Soil from Red River Valley.[5]		Virgin prairie.[5]			Pine forest soil.		Oak timbered soil.		Peaty soil.	Avr. 200 fertile soils.
	Surface. Per cent.	Subsoil. Per cent.	Surface. 1 to 6 inches. Per cent.	Subsoil. 6 to 12 inches. Per cent.	Subsoil. 30 to 36 inches. Per cent.	Surface. Per cent.	Subsoil. Per cent.	Surface. Per cent.	Subsoil. Per cent.	Per cent.	Surface. Per cent.
Insoluble matter	47.64	41.21	72.30	73.95	74.99	94.65	95.58	79.90	79.72	18.47	79.95
Silica (sol. in Na_2CO_3)	15.43	8.37	6.77	6.58	7.48	...	...	...	...	...	...
Potash	0.54	0.25	0.45	0.40	0.64	0.16	0.15	0.26	0.35	0.32	0.29
Soda	0.45	0.48	0.26	0.42	0.31	0.22	0.27	0.09	0.13	0.20	0.25
Lime	2.44	7.45	0.69	0.70	3.21	0.47	0.35	c.76	0.23	0.51	2.16
Magnesia	1.85	4.48	0.38	0.36	0.91	0.24	0.19	0.81	0.19	0.10	0.55
Iron oxide	4.18	3.48	2.93	3.05	5.79	1.21	1.21	2.43	4.15	2.60	2.68
Alumina	7.89	10.72	3.19	4.63	2.91	1.29	1.54	5.02	7.34	1.38	5.20
Phosphoric anhydride	0.38	0.17	0.35	0.26	0.17	0.13	0.09	0.30	0.11	0.32	0.24
Sulphuric "	0.11	0.10	0.06	0.04	0.05	0.10	0.05	0.05	0.03	1.06	0.03
Carbonic "	2.42	14.26	0.55	0.36	2.45	0.04	0.04	0.16	0.06	1.77	1.12
Volatile matter	15.55	6.22	10.90	9.12	8.27	1.51	0.74	8.68	7.02	71.80	7.00
Total	98.88	97.19	98.83	99.87	99.34	100.02	100.21	98.46	99.33	98.53	99.47
Volatile matter containing:											
Humus	5.34	0.89	5.12	...	...	0.47	...	2.48	...	...	3.35
Nitrogen	0.38	0.11	0.38	0.22	0.09	0.04	0.02	0.24	0.08	0.62	0 29

	Cotton soil.[31] S. C. sea coast.		Brazos River soil.[32] Texas.		Washington[33] surface soil.	Kentucky soil.[34]		California[35] fruit soil.	
	Surface.	Subsoil.	Surface	Subsoil.		Virgin.	Cultivated.	Surface.	Subsoil
Insoluble matter	93.61	94.46	68.45	77.57	76.49	77.01	81.01	72.72	73.57
Silica (soluble in Na_2CO_3)	1.63	1.89	14.79	0.84	13.66	9.33	...	14.53	6.44
Potash	0.05	0.14	1.10	0.44	0.63	0.30	0.32	0.68	1.35
Soda	0.11	0.15	0.23	1.82	0.37	0.39	0.19	0.24	0.25
Lime	0.03	0.02	5.62	0.18	1 08	0.40	0.32	1.15	0.57
Magnesia	0.04	0.04	1.86	3.18	0.72	0.34	0.39	1.30	0.87
Iron oxide	0.40	0.34	3.21	8.28	4.55	3.30	2.96	9.29	4.93
Alumina	1.93	2.52	7.68	0.13	7.52	6.70	5.92	8.29	8.72
Phosphoric anhydride	0.03	0.01	0.14	...	0.14	0.50	0.38	0.12	0.07
Sulphuric "	trace	trace	0.05	...	...	0.17	0.16	0.07	0.04
Carbonic "	...	...	3.99	1.71	...	0.10	0.06	...	...
Volatile matter	1.69	1.04	2.50	2.50	3.61	10.59	8.33	6.09	2.91
Humus	0.70	...	...	...	0.99	2.21	2.01	1.09	...
Nitrogen	...	...	...	...	0.10	0.27	0.18	...	...

93. Alkaline Soils. — When a soil contains such an excessive amount of alkaline salts as sodium sulphate, sodium or potassium carbonate or chloride, as to be destructive to vegetation, it is called an 'alkali' soil. These soils are found in semi-arid regions, and wherever conditions have been such that the alkaline compounds have not been drained from the soil. Occasionally calcium chloride is the destructive material. Chlorine in any ordinary combination is destructive to vegetation when present to the extent of more than 1 part per 1000 parts of soil. Of the various alkaline compounds potassium carbonate is one of the most injurious. Sodium sulphate is a milder form of alkali. When evaporation takes place the alkaline compounds are deposited as a coating on the surface of the soil. Many soils supposed to be strongly alkaline, because a white coating is formed on the surface, simply contain so much lime carbonate that a deposit is formed. Many excellent soils have been passed over as 'alkali' soils when in reality they are limestone soils.

94. Improving 'Alkali' Soils.[26] — When a large tract of alkali is to be brought under cultivation the amount of prevailing alkaline compounds should be determined by chemical analysis. It frequently happens that deep and thorough cultivation are all the treatment that is necessary. If the prevailing alkali is sodium carbonate a dressing of land plaster may be applied so as to change the alkali from sodium carbonate to sodium sulphate, a less destructive form, the reaction being:

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4.$$

Many shrubs, as greesewood, and weeds, as Russian thistle, take from the soil large amounts of alkaline matter, and it is sometimes advisable to remove a number of such crops so as to reduce the alkali. A slightly beneficial effect is sometimes noticed on small 'alkali' spots where the ashes from straw are used, forming potassium silicate. As a rule ashes are more injurious than beneficial, on an 'alkali' soil. Irrigation and thorough drainage, if continued long enough, will effect a permanent cure. Irrigation without drainage may cause a more alkaline condition by bringing to the surface subsoil alkali. The waters from some streams and wells are unsuited for irrigation on account of containing too much alkaline matter. Mildly alkaline soils will usually repay in crop production all the labor which is expended in making them productive, and when brought under cultivation are frequently very fertile soils. A small amount of alkaline compounds in a soil is beneficial; in fact, many soils would be more productive if they contained more alkaline matter.

95. Improving Small Tracts of 'Alkali' Land.— When the places are located so that they can be underdrained at comparatively little expense, this should be done, as it will prove the best and most permanent way of removing the alkali. Good surface drainage should also be provided. Quite frequently a quarter or a third of the total alkali in the soil will, in a dry time, be found near and on the surface. In such cases, and if the spots are small, a large amount of alkali can be removed by scraping the surface and then carting the scrapings away and dumping them where they can do no damage.

When preparing an 'alkali' spot for a crop, deep plowing should be practiced, so as to open up the soil and remove the excess of alkaline matter from the surface. Where manure, particularly horse manure, can be obtained these spots should be manured very heavily. The horse manure, when it decomposes, furnishes acid products, which combine with the alkaline salts. The manure also prevents rapid surface evaporation. Oats are about the safest grain crop to seed on an 'alkali' spot because the oat plant is capable of thriving in an alkaline soil where many other grain crops fail.

'Alkali' soils are usually deficient in available nitrogen. The organism which carries on the work of changing the humus nitrogen to available forms cannot thrive in a strong alkaline solution. In many of these soils, as demonstrated in the laboratory, nitrification cannot take place. After thorough drainage and preparation for a crop, a few loads of good soil from a fertile field sprinkled on 'alkali' spots will do much to encourage nitrification, by introducing the nitrifying organisms.

THE ORGANIC COMPOUNDS OF SOILS

96. Sources of the Organic Compounds of Soils. — The organic compounds of soils are derived from accumulated vegetable and animal matter which has been acted upon by micro-organisms. The organic matter of the soil originally consisted of the same compounds, as cellulose, proteid bodies, and organic acids that are found in living plants and animals. By the action of various micro-organisms the cellulose, proteid bodies, and other compounds have undergone chemical changes, and produced the organic compounds of the soil which are mixtures of animal and vegetable matter in various states of decomposition. The organic compounds of the soil may exist in various forms ranging from cellulose to the final oxidation products as carbon dioxide and water.[27]

97. Classification of the Organic Compounds. — Various attempts have been made to classify the organic compounds of the soil, but those which have been described are without doubt mixtures of various bodies, and not distinct compounds. An old classification by Mülder[28] was humic, ulmic, crenic, and approcrenic acids. This classification does not include any nitrogenous matter containing more than four per cent. nitrogen, while organic matter with eight to ten per cent. and in some cases eighteen per cent. of nitrogen is quite frequently met with; hence this classification is incomplete as it includes only a part of the organic compounds of the soil.

98. **Humus.** — The term humus is employed to designate what are considered to be the most active principles of the organic compounds. Humus is the animal or vegetable matter of the soil in intermediate forms of decomposition. From different soils, it is extremely varied in composition: in one soil it may have been derived mainly from cellulose, while in another it may have been derived from a mixture of cellulose, proteid bodies, and other organic compounds. The term humus, unless qualified, is a very indefinite one. The humus given in the analyses of soils is obtained by extracting the soil with a dilute alkali as ammonium hydroxide, after treating the soil with a dilute acid to remove the lime which renders the humus insoluble.

99. **Humification and Humates.** — When the animal and vegetable matter incorporated into soils undergoes decomposition there is a union of the organic compounds and the base-forming elements of the soil. The decaying organic matter produces organic products of an acid nature. The organic acids and the base-forming products unite to form humates or organic salts, which are neutral bodies. This process is humification.[17]

Humic acid + calcium carbonate = calcium humate + CO_2.
Humic acid + potassium sulphate = potassium humate, etc.

The fact that a union occurs between the organic matter and the soil has been demonstrated by mixing with soils known amounts of various organic materials, as cow manure, green clover, meat scraps, and sawdust, and allowing humification to go on for a year or more. After humification has taken place, the humus extracted from the soil contains more potash, phosphoric acid, and other elements than were present in the humus of the original soil and humus-forming material, showing that a chemical union has taken place between the decaying organic matter and the soil. The power of various organic substances to produce humates is illustrated in the following table :[29]

	Humic phosphoric acid. Grams.	Humic potash. Grams.
Cow manure humus :		
In original manure and soil	1.17	1.06
In final humus product (after humification)	1.62	1.27
Gain in humic forms	0.45	0.21
Green clover humus :		
In original soil and clover	3.21	5.26
In final humus product	3.74	4.93
Gain in humic forms	0.53	(Loss) 0.33
Meat scrap humus :		
In original meat scraps and soil	1.07	0.25
In final humus product	1.18	0.36
Gain	0.11	0.11

	Humic phosphoric acid. Grams.	Humic potash. Grams.
Sawdust humus:		
In original sawdust and soil	0.85	0.67
In final humus product	0.78	0.70
Oat straw humus:		
In original straw and soil	1.02	2.42
In final humus product	1.03	2.41

100. Comparative Value and Composition of Humates. — The humus produced from nitrogenous bodies, as meat scraps, is more valuable than that produced from cellulose bodies as sawdust, because the former have a greater power of combining with the phosphoric acid and potash of the soil. The non-nitrogenous compounds, as cellulose, starch, and sugar, undergo fermentation but seem to possess little, if any, power to form humates. There is also a great difference in soils as to their humus-producing powers. Soils deficient in lime or alkaline compounds possess only a feeble power to produce humates. There is also a marked variation in the composition of the humus produced from different kinds of organic matter. Straw, sawdust, and sugar, materials rich in cellulose and other carbohydrates, yield a humus characteristically rich in carbon and poor in nitrogen. Materials rich in nitrogen, like meat scraps, green clover, and manure, produce a more valuable humus, rich in nitrogen and possessing the power to combine with the potash and phosphoric acid of the soil to form humates.

COMPOSITION OF HUMUS PRODUCED BY[29]

	Cow manure.	Green clover.	Meat scraps.	Wheat flour.	Oat straw.	Saw-dust.	Sugar.
Carbon	41.95	54.22	48.77	51.02	54.30	49.28	57.84
Hydrogen	6.26	3.40	4.30	3.82	2.48	3.33	3.04
Nitrogen	6.16	8.24	10.96	5.02	2.50	0.32	0.08
Oxygen	45.63	34.14	35.97	40.14	40.72	47.07	39.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Highest.		Lowest.		Difference.
Carbon	57.84	Sugar	41.95	Cow manure	15.89
Hydrogen	6.26	Cow manure	2.48	Oat straw	3.78
Nitrogen	10.96	Meat scraps	0.08	Sugar	10.88
Oxygen	47.07	Sawdust	34.14	Green clover	12.93

The differences in composition are noticeable. The humus produced by each material as green clover, oat straw, or sawdust is different from that produced by any other material. The humus from green clover is undoubtedly very complex in nature, because it contains both nitrogenous and non-nitrogenous compounds, and each class has a different action in humification processes, hence it follows that the humus from the green clover must be a complex mixture of both nitrogenous and non-nitrogenous bodies.

The nature of the humus, whether nitrogenous or non-nitrogenous, is important. Humus produced from sawdust and humus from meat scraps may be taken respectively as types of non-nitrogenous and nitrogenous humus.

101. Value of Humates as Plant Food.—Various opinions have been held regarding the actual value, as plant food, of this product from partially decayed animal and vegetable matter. Humus was formerly regarded as composed only of carbon, hydrogen, and oxygen, and inasmuch as plants obtain these elements from water and from the carbon dioxide of the air, no value was assigned to humus. Later investigators added nitrogen to the list but stated that the nitrogen, when combined with the humus and before undergoing fermentation, was of no value as plant food.

Recent investigations have proved that the phosphoric acid and other mineral elements combined with the organic matter of soils are of value as plant food,[16] and it has been demonstrated that crops grown on the black soils of Russia obtain a large part of their mineral food from organic combinations.[83] Culture experiments have shown that under normal conditions plants like oats and rye may obtain their mineral food entirely from humate sources. Seeds when planted in a mixture of pure sand and neutral humates from fertile soils, produced normal plants. In order to secure the best conditions for growth, a little lime must be present to prevent the formation of humic acid, and the usual organisms found in fertile fields must also be introduced. The following example is given of oats grown under such conditions:

NITROGEN AND ASH ELEMENTS.[16]

	In six oat seeds. Gram.	In six mature plants. Gram.
Nitrogen	0.0040	0.0556
Potash	0.0013	0.0640
Soda	0.0001	0.0079
Lime	0.0002	0.0249
Magnesia	0.0005	0.0110
Iron	.....	0.0064
Phosphoric anhydride	0.0016	0.0960
Sulphuric anhydride	0.0001	0.0090
Silicon	0.0026	0.7300

The fact that plants feed on humate compounds, and that decaying animal and vegetable matter produce humates from the inert potash and phosphoric acid of the soil, has an important bearing upon crop production, because it indicates a way by which inert plant food may be converted into more active forms. It also explains that stable manure is valuable because it makes the inert plant food of the soil more available.

102. Amount of Plant Food in Humate Forms.— In a prairie soil containing three and five-tenths per cent. of humus there are present 100,000 pounds of humus per acre. Combined with this humus there are from 1,000 to 1,500 pounds each of phosphoric acid and potash. Soils which have been under long cultivation without the restoration of any humus contain from 300 to 500 pounds each of humic potash and phosphoric acid.[17] A decline in crop-producing power has in many cases been brought about by the destruction of the humus.

103. Loss of Humus. — The loss of humus from the soil is caused by oxidation and by fires. Any method of cultivation which accelerates oxidation reduces the humus content. In many of the western prairie soils which have been under continuous grain cultivation for thirty years and more, the amount of humus has been reduced one-half. Summer fallowing also causes a loss of humus. When land is continually under the plow, and no manures are used, the humus is rapidly oxidized, and there is left, in the soil, organic matter which is slow to decay.

Forest and prairie fires have been very destructive to the organic compounds of the soil. A soil from Hinckley, Minn., before the great forest fire of 1893 showed 1.69 per cent. humus and 0.12 per cent. nitrogen.[17] After the fire there were present 0.41 per cent. humus and 0.03 per cent. nitrogen. The forest fire caused a loss of 2,500 pounds of nitrogen per acre. In clearing new land, particularly forest land, there is frequently an unnecessary destruction of humus materials. Instead of burning all of the vegetable matter it would be better economy to leave some in piles for future use as manure. When all of the vegetable matter has been burned two or three good crops are obtained but the permanent crop-producing power of the land is reduced because of the loss of nitrogen. When the vegetable matter has been only partially removed the crops at first may be smaller, but in a few years returns will be greater than if all of the vegetable matter were burned.

104. Physical Properties of Soils Influenced by Humus. — The physical properties of a soil may be entirely changed by the addition or the loss of humus. The influence of humus upon the weight, color, water, and heat of soils, is discussed in the chapter on the physical properties of soils. Soils reduced in humus content have less power of storing up water and resisting drought. This fact is illustrated in the following table:[30]

PER CENT. WATER.

	In soil.	After 10 hours exposure in tray, to sun.
Soil rich in humus (3.75 per cent.)	16.48	6.12
Adjoining soil poorer in humus (2.50 per cent.)	12.14	3.94

105. Humic Acid. — In the absence of calcium carbonate or other alkaline compounds, the vegetable matter may produce acid products destructive to the growth of some crops. The acidity in such cases may be readily corrected by the use of lime or wood ashes. Studies conducted by the Rhode Island Experiment Station indicate that the areas of acid soils are quite extensive. Acid soils can be distinguished by their action upon red litmus paper. A soil may, however, give an acid reaction and contain a fair amount of lime. The subject of acid soils and liming is considered in Chapter IX.

106. Soils in Need of Humus. — Sandy and sandy loam soils that have been cultivated for a number of years to corn, potatoes, and small grains, without the use of stable manures or the proper rotation of crops, are deficient in humus. Clay soils, as a rule, do not stand in need of humus so much as loam or sandy soils. The mechanical condition of heavy clays is,

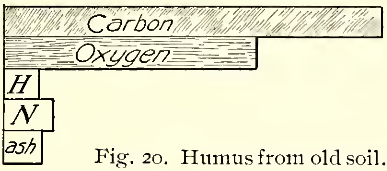


Fig. 20. Humus from old soil.

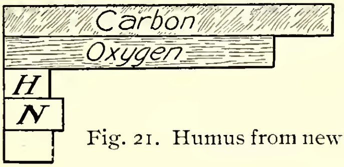


Fig. 21. Humus from new soil.

however, improved by the addition of humus-forming material. 'Alkali' soils are usually deficient in humus. Its addition to loam or sandy soils is beneficial in preventing the soil from drifting because humus binds together the soil particles. There are but few soils, under ordinary cultivation, to which it is not safe to add humus-forming materials. Ordinary prairie soils, for the first ten years after breaking, are usually well supplied. Swampy, peaty, and muck soils contain large amounts; in fact, they are often overstocked with humus.

107. Active and Inactive Humus.—When soil has been under long cultivation, and no manures have been used, the nitrogen and mineral matters combined with the humus are reduced. The humus from long cultivated fields contains a higher per cent. of carbon than that from well-manured or new land; it is also less active because of the higher per cent. of carbon which does not readily undergo oxidation.[17]

	Humus from new soil. Per cent.	Humus from old soil. Per cent.
Carbon	44.12	50.10
Hydrogen	6.00	4.80
Oxygen	35.16	33.70
Nitrogen	8.12	6.50
Ash	6.60	4.90
Total humus material	5.30	3.38

108. Influence of Different Methods of Farming upon Humus.—The general system of farming has a direct effect upon the humus content and composition of the soil. Where live stock is kept, the manure properly used, and the crops systematically rotated, the crop-producing power of the land is not decreased, as in the case of the one-crop system. The influence of different systems of farming upon the humus content and other properties of the soil may be observed from the following table:[30]

Character of soil.	Weight per cu. ft. lbs.	Humus. Per cent.	Nitrogen. Per cent.	Phosphoric acid combined with humus. Per cent.	Water-holding capacity. Per cent.
1. Cultivated thirty-five years; rotation of crops and manure; high state of productiveness	70	3.32	0.30	0.04	48
2. Originally same as 1; continuous grain cropping for thirty-five years; low state of productiveness	72	1.80	0.16	0.01	39
3. Cultivated forty-two years; systematic rotation and manure; good state of productiveness	70	3.46	0.26	0.03	59
4. Originally same as 3; cultivated thirty-five years; no systematic rotation or manure; medium state of productiveness	67	2.45	0.21	0.03	57

CHAPTER IV

NITROGEN OF THE SOIL AND AIR, NITRIFICATION, AND NITROGENOUS MANURES

109. Importance of Nitrogen as a Plant Food. — The illustration (Fig. 22) shows an oat plant which has received no nitrogen, while potash, phosphates, lime, and all other essential elements of plant food were liberally supplied. Observe the peculiar and restricted growth, with but little root development. The leaves were yellowish in color.

Fig. 22. Oat plant grown without nitrogen.

In the absence of nitrogen a plant makes no appreciable growth. With only a limited supply, a plant begins its growth in a normal way but as soon as the available nitrogen is used up, the lower and smaller leaves begin gradually to die down from the tips, and all of the plant's energy is centered in one or two leaves. In one experiment when only a small amount of nitrogen was supplied, the plant struggled along in this way for about nine weeks, making a total growth of but six and one-half inches.[16] Just at the critical point when the plant was dying of nitrogen starvation, a few milligrams of calcium nitrate were given. In thirty-six hours the plant showed signs of renewed life, the leaves assumed a deeper green, a new growth was begun, and finally four seeds were produced. During the time of seed formation more nitrogen was added, but with no beneficial result. All of the essential elements for plant growth were liberally provided, except nitrogen which was very sparingly supplied at first, until near the period of seed formation, when it was more liberally supplied.

When plants have reached a certain period in their development, and have been starved for the want of nitrogen, the later application of this element does not produce normal growth, as the energies of the plant have been used up in searching for food. Nitrogen, as well as potash, lime, and phosphoric acid, are all necessary while plants are in their first stages of growth.

In the case of wheat, nitrogen is assimilated more rapidly than are any of the mineral elements. Before the plant heads out, over eighty-five per cent. of the total nitrogen required has been taken from the soil.[36] Corn also takes up all of its nitrogen from four to five weeks before the crop matures. Flax takes up seventy-five per cent. of its nitrogen during the first fifty days of growth.[37]

Nitrogen is demanded by all crops. It forms the chief building material for the proteids of all plants. In the absence of a sufficient amount of nitrogen, the rich green color is not developed; the foliage is of a yellowish tinge. Nitrogen is one of the constituents of chlorophyl, the green coloring-matter of plants, hence with a lack of nitrogen only a limited amount of chlorophyl can be produced. Plants with large, well-developed leaves of a rich, green color are not suffering for nitrogen. Nitrogenous fertilizers have a tendency to produce a luxurious growth of foliage deep green in color.

ATMOSPHERIC NITROGEN AS A SOURCE OF PLANT FOOD

110. Early Views. — In addition to the carbon, hydrogen, and oxygen, which form the organic compounds of plants, nitrogen also, at the beginning of the present century, was known to be present. The sources of carbon, hydrogen, and oxygen, for crop purposes, were much easier to determine and understand than the sources of nitrogen. Priestley, the discoverer of oxygen, believed that the free nitrogen of the air was a factor in supplying plant food. De Saussure arrived at just the opposite conclusion. The facts which led to these beliefs were not convincing because the methods of chemical analysis had not yet been sufficiently perfected to solve the question.[38]

111. Boussingault's First Experiments.—Boussingault was the first to make a careful study of the subject. In a prepared soil, free from nitrogen, and containing all of the other elements necessary for plant growth, he grew clover, wheat, and peas, carefully determining the nitrogen in the seed. The plants were allowed free access to the air, being simply protected from dust, and were watered with distilled water. But little growth was made. At the end of two months the plants were submitted to chemical analysis, and the amount of nitrogen present was determined.

His first results are given in the following table:[39]

NITROGEN.

	In seed sown. Gram.	In plant. Gram.	Gain. Gram.
Clover, 2 mos.	0.11	0.12	0.01
" 3 "	0.114	0.156	0.042
Wheat 2 "	0.043	0.04	—0.003
" 3 "	0.057	0.06	0.003
Peas 2 "	0.047	0.10	0.053

Boussingault concluded that when plants, in a sterile soil, were exposed to the air, there was with some a slight gain of nitrogen but the amount gained from atmospheric sources was not sufficient to feed the plant and allow it to reach full maturity. By many these results were not accepted as conclusive.

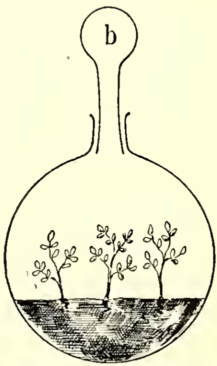


Fig. 23. Plants grown in carboy.

112. Boussingault's Second Experiments.—Fifteen years later (1853) Boussingault repeated his experiments in a different way. The plants were grown in a large carboy with a limited volume of air so as to cut off all sources of combined nitrogen, as ammonia. By means of a second glass vessel (*b*, Fig. 23) the carboy was kept supplied with a liberal amount of carbon dioxide, so that plant growth would not be checked for lack of this material. When experiments were carried on in this way using a fertile soil, the plants reached full maturity, but when a soil free from nitrogen was used, plant growth was soon checked. A general summary of this work is given in the following table:[39]

NITROGEN.

	In seeds. Gram.	In plant. Gram.	Loss. Gram.
Dwarf beans	0.1001	0.0977	—0.0024
Oats	0.0109	0.0097	—0.0012
White lupines	0.2710	0.2669	—0.0041
Garden cress	0.0013	0.0013	......

These experiments show that with a sterilized soil, and all sources of combined atmospheric nitrogen cut off, the free nitrogen of the air takes no part in the food supply of the plant.

113. Boussingault's Third Experiments.—In 1854 Boussingault again repeated his experiments; this time he grew the plants in a glass case so constructed that there was a free circulation of air from which all combined nitrogen had been removed. These experiments were similar to his second series; the plants, however, were not grown in a limited volume of air. The results, without going into detail, showed that the free nitrogen of the air, under the conditions of the experiment, took no part in the food supply of plants.

If anything, there was less nitrogen recovered in the dwarfed plants than there was in the seed sown.

114. Ville's Results. — About the same time Ville carried on a series of experiments of like nature, but in a different way, and arrived at just the opposite conclusions. In short, his experiments indicated that plants were capable of making liberal use of the free nitrogen of the air for food purposes. The directly opposite conclusions of Boussingault and Ville, led to a great deal of controversy. The French Academy of Science took up the question, and appointed a commission to review the work of Ville. The commission consisted of six prominent scientists. They reported that "M. Ville's conclusions are consistent with his labor and results."[38]

115. Work of Lawes and Gilbert. — Lawes and Gilbert, however, carried on such extensive experiments under a variety of conditions as to remove all doubt regarding the question. Plants were grown in sterilized soils, in prepared pumice stone, and in soils with a limited and known quantity of nitrogen beyond that contained in the seed. Different kinds of plants were experimented with. The work was carried on with the utmost care and with apparatus so constructed as to eliminate all controllable factors. The results in the aggregate clearly indicate that plants, when acting in a sterile medium, are unable to make use of the free nitrogen of the air for the production of organic matter.[38]

116. Atwater's Experiments. — Atwater carried on similar experiments in this country.[40] Some of his results indicate that when seeds germinate they lose a small part of their nitrogen, and when grown in a sterile soil, they fail to fix any of the free nitrogen of the air.

In all of the work of the different investigators prior to 1888, plants were grown in a sterilized medium, and under these conditions they are unable to make use of the free nitrogen of the air.

117. Field and Laboratory Tests. — Experiments with sterilized soils do not represent the normal conditions of growing crops, where all of the bacteriological agencies of the soil, the air, and the plant, are free to act. Experiments have shown that these agencies have an important bearing upon plant growth.

In a five years' rotation of clover and other leguminous plants, Lawes and Gilbert found that a soil gained from two to four hundred pounds of nitrogen in addition to that removed in the crop, while land which produced wheat continuously had gradually lost nitrogen. The amount in the subsoil remained nearly the same. All of these facts plainly indicated that crops like clover have the power of gaining nitrogen from unknown sources. The results of prominent German agriculturists led to the same conclusion. It was known that wheat grown after clover gave as good results as the use of nitrogenous manure for the wheat, but for many years this fact was unexplained.

118. Hellriegel's Experiments. — He grew leguminous plants in nitrogen-free soils. One set of plants was watered with distilled water, while another had in addition small amounts of leachings from an old loam field. The plants watered with distilled water alone made but little growth, while those watered with the loam leachings reached full maturity and contained something like a hundred times more nitrogen than was in the seed sown. The dark green color was also developed, showing the presence of a normal amount of chlorophyl. The roots of the plants had well-developed swellings or nodules, while those that were watered with distilled water alone had none. The loam leachings contained only a trace of nitrogen.[41]

119. Experiments of Wilfarth. — Experiments by Wilfarth give more exact data regarding the amount of nitrogen taken from the air. Lupines were grown in the same way, and one lot watered with distilled water, while another lot received in addition leachings from an old lupine field.

Watered with distilled water.		Watered with soil leachings.	
Dry matter. Grams.	Nitrogen. Gram.	Dry matter. Grams.	Nitrogen. Grams.
0.919	0.015	44.72	1.099
0.800	0.014	45.61	1.153
0.921	0.013	44.48	1.195
1.021	0.013	42.45	1.337

These experiments have been verified by many other investigators until the fact has been established that leguminous plants may, through the agency of micro-organisms, make use of the free nitrogen of the air. The work of Hellriegel was not accidental but the result of careful and systematic investigation. As early as 1863 he observed that clover would develop along the roadway in sand in which there was scarcely a trace of combined nitrogen.

120. Composition of Root Nodules.—The root nodules referred to, are particularly rich in nitrogen. In one experiment, the light-colored and active ones contained 5.55 per cent. of nitrogen while the dark-colored and older ones contained 3.21 per cent. The entire nodules of the root both active and inactive contained 4.60 per cent. nitrogen. The root itself contained 2.21 per cent. nitrogen.[42]

The root nodules also contain definite and characteristic micro-organisms, and it was the spores of these organisms that were present in the soil extract in both Hellriegel's and Wilfarth's experiments. In the sterilized soils they were not present. These organisms found in root nodules, are the essential agents which aid in the fixation of the free nitrogen of the air, and in its ultimate use as plant food.

121. Nitrogen in the Root Nodules Returned to the Soil.—Ward has shown that when clover roots decay, the organisms and nitrogen present in the nodules are distributed within the soil.[38] Hence whenever a leguminous crop is raised, nitrogen is added to the soil, instead of being taken away, as in the case of a grain crop. The amount of nitrogen per acre returned to the soil by a leguminous crop as clover, varies with the growth of the crop. In the roots of a clover crop a year old there are present from 20 to 30 pounds of nitrogen per acre, while in the roots and culms of a dense clover sod, two or three years old, there may be present 75 pounds or more of nitrogen. Peas, beans, lucern, cow peas, and all members of the leguminous family possess the power of fixing the free nitrogen of the air by means of micro-organisms. The micro-organisms associated with one species as clover differ from these associated with another as lucern. The amount of nitrogen which the various legumes return to the soil is variable. Hellriegel's results are of the greatest importance to agriculture because they show how the free nitrogen of the air can be utilized indirectly as food, by crops unable to appropriate it for themselves.

THE NITROGEN COMPOUNDS OF THE SOIL

122. Origin of the Soil Nitrogen.—The nitrogen of the soil is derived chiefly from the accumulated remains of animal and vegetable matter. The original source of the soil nitrogen, that is the nitrogen which furnished food to support the vegetation from which our present stock of soil nitrogen is obtained, was probably the free nitrogen of the air. All of the ways in which the free nitrogen of the air has been made available to plants of higher orders which require combined nitrogen, are not known. It is supposed, however, that this has been brought about by the workings of lower forms of plant life, and by micro-organisms. Whatever these agencies have been they do not appear to be active in a soil under high cultivation, because the tendency of ordinary cropping is to reduce the supply of soil nitrogen.

123. **Organic Nitrogen of the Soil.** — In ordinary soils the nitrogen is present mainly in organic forms combined with the carbon, hydrogen, and oxygen; and to a less extent with the mineral elements forming nitrates. The organic forms of nitrogen, it is generally considered, are incapable of supplying plants with nitrogen for food purposes until the process known as nitrification takes place. The nitrogenous organic compounds in cultivated soils are derived mainly from the undigested protein compounds of manure and from the nitrogenous compounds in crop residues. When decomposition occurs, amides, organic salts, and other allied bodies are without doubt produced as intermediate products before nitrification takes place. The organic nitrogen of the soil may be present in exceedingly inert forms similar to leather. In fact in many peaty soils there are large amounts of inactive organic compounds rich in

nitrogen. In other soils the nitrogen is present in less complex forms. The organic nitrogen of the soil may vary in complexity from forms like the nitrogen of urea to forms like that of peat.

124. Amount of Nitrogen in Soils. — The fertility of any soil is dependent, to a great extent, upon the amount and form of its nitrogen. In soils of the highest degree of fertility there is usually present from 0.2 to 0.3 per cent. of total nitrogen, equivalent to from 7,000 to 10,000 pounds per acre to the depth of one foot. Many soils of good crop-producing power contain as low as 0.12 per cent. of nitrogen. There is usually two or three times more nitrogen in the surface soil than in the subsoil. In many sandy soils which have been allowed to decline in fertility the nitrogen may be less than 0.04 per cent. Of the total nitrogen in soils there is rarely more than 2 per cent. at any one time, in forms available as plant food.[43] A soil with 5,000 pounds of total nitrogen per acre would contain about 100 pounds of available nitrogen of which only a part comes in contact with the roots of crops. Hence it is that a soil may contain a large amount of total nitrogen and yet be deficient in available nitrogen.

125. Amount of Nitrogen Removed in Crops. — The amount of nitrogen removed in crops ranges from 25 to 100 pounds per acre depending upon the nature of the crop. It does not necessarily follow that the crop which removes the largest amount of nitrogen leaves the land in the most impoverished condition. Wheat and many grains, while they do not remove such a large amount of nitrogen in the crop, leave the soil more exhausted than if other crops were grown. This, as will be explained, is caused by the loss of nitrogen from the soil in other ways than through the crop.[37]

	Pounds of nitrogen per acre.
Wheat, 20 bushels	25
Straw, 2000 pounds	10
Total	35
Barley, 40 bushels	28
Straw, 3000 pounds	12
Total	40
Oats, 50 bushels	35
Straw, 3000 pounds	15
Total	50
Flax, 15 bushels	39
Straw, 1800 pounds	15
Total	54
Potatoes, 150 bushels	40
Corn, 65 bushels	40
Stalks, 3000 pounds	35
Total	75

126. Nitrates and Nitrites.—The amount of nitrogen in the form of nitrates and nitrites, varies from mere traces to 150 pounds per acre. Calcium nitrate is the usual form met with, especially in soils which are sufficiently supplied with calcium carbonate to allow nitrification to progress rapidly. Nitrates and nitrites are the most valuable forms of nitrogen for plant food. Both are produced from the organic nitrogen of the soil. A nitrate is a compound composed of a base element as sodium, potassium, or calcium, combined with nitrogen and oxygen. A nitrite contains less oxygen than a nitrate.

Potassium nitrate, KNO_3, sodium nitrate, $NaNO_3$, and calcium nitrate, $Ca(NO_3)_2$, are the nitrates which are of most importance in agriculture. The nitrites, as potassium nitrite, KNO_2, are met with to a less extent than the nitrates. Nitrates and nitrites are present in surface well waters contaminated with animal and vegetable matter. Many well waters possess some material value as a fertilizer on account of the nitrates, nitrites, and decaying animal and vegetable matters which they contain.

127. Ammonium Compounds of the Soil. — The amount of ammonium compounds in a soil is usually less than the amount of nitrates and nitrites. The sources of the ammonium compounds are: rain-water and the ammonia formed from the decay of the organic matter. Like the nitrates and nitrites, the ammonium compounds are all soluble and hence cannot accumulate in soils which receive an average amount of rainfall. They are usually found in all surface well waters. In the soil, the ammonium compounds may be oxidized and form nitrates. Compounds as ammonium chloride or ammonium carbonate, if present in a soil in excessive amounts, will destroy vegetation in a way similar to the alkaline compounds in alkaline soils.

128. Nitrogen in Rain-water and Snow.—The amount of nitrogen which is annually returned to the soil in the form of ammonium compounds dissolved in rain-water and snow, is equivalent to from 2 to 3 pounds per acre. At the Rothamsted experiment station the average amount for eight years was 3.37 pounds.[43] When a soil is rich in nitrogen the gain from rain and snow is only a partial restoration of that which has been given off from the soil to the air or lost in the drain waters. The principal form of the nitrogen in rain water is ammonium carbonate which is present in the air to the extent of about 22 parts per million parts of air.

129. Ratio of Nitrogen to Carbon in the Organic Matter of Soils.—In some soils the organic matter is more nitrogenous than in others. In those of the arid regions the humus contains from 15 to 20 per cent. of nitrogen, while soils from the humid regions contain 4 to 6 per cent.[44] In some soils the ratio of nitrogen to carbon may be 1 to 6, while in others it may be 1 to 18 or more. That is, in some soils there is 1 part of nitrogen to 6 parts of carbon, while in others the organic matter contains 1 part of nitrogen to 18 parts of carbon. In a soil where there exists a wide ratio between the nitrogen and carbon, it is believed that the conditions for supplying crops with available nitrogen are unfavorable.

130. Losses of Nitrogen from Soils. — When a soil rich in nitrogen is cultivated for a number of years exclusively to grain crops there is a loss of nitrogen exceeding the amount removed in the crop, caused by the rapid oxidation of the organic matter of the soil. Experiments have shown that when a soil of average fertility is cultivated continually to grain that for every 25 pounds of nitrogen removed in the crop there is a loss of 146 pounds from the soil due to the destruction of the organic matter.[17] In general, any system of cropping which keeps the soil continually under the plow, results in decreasing the nitrogen. When a soil is rich in nitrogen the greatest losses occur; when poor in nitrogen there is relatively less loss. There is a tendency toward the establishment of an equilibrium as to the nitrogen content of soils. When a soil rich in nitrogen is given arable culture the oxidation of the organic matter and the losses of nitrogen take place rapidly.

131. Gain of Nitrogen in Soils. — When arable land is permanently covered with vegetation, there is a gain of nitrogen. Pasture land contains more nitrogen than cultivated land of a similar character; also in meadow land there is a tendency for the nitrogen to increase. These facts are well illustrated in the investigations of Lawes and Gilbert, at Rothamsted.[43]

	Age of pasture. Years.	Nitrogen. Per cent.
Arable land	..	0.14
Barn-field pasture	8	0.151
Apple-tree pasture	18	0.174
Meadow	21	0.204
Meadow	30	0.241

After deducting the amount of nitrogen in the manure added to the meadow land, the annual gain of nitrogen was more than 44 pounds per acre.

Another source of gain of nitrogen is the fixation of the free nitrogen of the air by the growth of clover and other leguminous crops. If a soil is properly manured and cropped the amount of nitrogen may be increased. A rotation of wheat, clover, wheat, oats, and corn with manure will leave the soil at the end of the period of rotation in better condition as regards nitrogen than at the beginning. These facts are illustrated in the following table:[17]

Continuous wheat culture—	
Nitrogen in soil at beginning of experiment	0.221 per cent.
Nitrogen at end of 5 years continuous wheat cultivation	0.193 " "
Loss per annum per acre (in crop 24.5, soil 146.5)	171 pounds.
Rotation of crops—	
Nitrogen in soil at beginning of rotation	0.221 per cent.
Nitrogen at close of rotation	0.231 " "
Gain to soil per annum per acre	61 pounds.
Nitrogen removed in crops per annum	44 "

It is to be regretted that in the cultivation of large areas of land to staple crops as wheat, corn, and cotton, the methods of cultivation are such as to decrease the nitrogen content and crop-producing power of the soil when this can be prevented.

NITRIFICATION

132. Former Views Regarding Nitrification.— The presence of nitrates and nitrites in soils was formerly accounted for by oxidation. The theory was held that the production of nascent nitrogen by the decomposition of organic matter caused a union between the oxygen of the air and the nitrogen of the organic matter. The studies of fermentation by Pasteur led him to believe that possibly the formation of nitric acid in the soil might be due to fermentation. It was, however, 15 years later before the French chemists, Schlösing and Müntz, established the fact that nitrification is produced by a living organism.

133. Nitrification Caused by Micro-organisms. — Nitrification is the process by which nitrates or nitrites are produced in soils, by the workings of organisms. Nitrification results in changing the complex organic nitrogen of the soil to the form of nitrates or nitrites. It is the process by which the inert nitrogen of the soil is rendered available as crop food. The organisms which carry on the work of nitrification have been isolated and studied by Warington, and by Winogradsky.

134. Conditions Necessary for Nitrification are:

1. Food for the nitrifying organisms.
2. A supply of oxygen.
3. Moisture.
4. A favorable temperature.
5. Absence of strong sunlight.
6. The presence of some basic compound.

In order to allow nitrification to proceed, all of these conditions must be satisfied. The process is frequently checked because some of the conditions, as presence of a basic compound, are unfulfilled.

135. Food for the Nitrifying Organisms.—All living organisms require a supply of food and one of the food requirements of the nitrifying organism is a supply of phosphates. In the absence of phosphoric acid, nitrification cannot take place. The change which the phosphoric acid undergoes in serving as food for the nitrifying organism is unknown, but it doubtless makes the phosphoric acid more available as plant food. The principal organic food of the nitrifying organism is the organic matter of the soil. Organic matter, only when incorporated with soil, can serve as food for the nitrifying organism. In the presence of a large amount of organic matter, as in a manure pile, nitrification does not take place. The process can take place only when the organic matter is largely diluted with soil. Under favorable condi-

FIG. 1. NITRIC ORGANISM IN POTASSIUM NITRITE SOLUTION.

FIG. 2. BACILLUS REDUCING NITRATES TO FREE NITROGEN GAS.

PLATE I.

tions nitrifying organisms may take all of their food as inorganic forms; that is, nitrification may take place in the absence of organic matter provided the proper mineral food be supplied. When growth under such conditions takes place the organisms assimilate carbon from the combined carbon of the air, and produce organic carbon compounds. That is, an organism, working in the absence of sunlight and unprovided with chlorophyl, may construct organic carbon compounds.[43] The nitrification which takes place in the absence of nitrogenous organic matter is of too limited a character to supply growing crops with all of their available nitrogen. For general crop production the organic matter of the soil is the source of the nitrogen which undergoes the nitrification process, and which furnishes food for the nitrifying organisms.

136. Oxygen Necessary for Nitrification.—The second requirement for nitrification is an adequate supply of oxygen. The nitrification organism belongs to that class of ferments (aerobic) which requires oxygen for existence. Oxygen is present as one of the elements in the final product of nitrification as in calcium nitrate, $Ca(NO_3)_2$. In the absence of oxygen the nitrification process is checked. When soils are saturated with water, the process cannot go on for want of oxygen. In well-cultivated soils, particularly clay soils, the conditions for nitrification are improved by aeration because the supply of oxygen in the soil spaces is increased.

137. Moisture Necessary for Nitrification. — Nitrification cannot take place in a soil deprived of moisture. As in all fermentation processes, so with nitrification, moisture is necessary for the chemical changes to take place. In a very dry time nitrification is arrested for the want of water. Water is as necessary for the growth and development of the living organism which carries on the work of nitrification, as it is to the life of a plant of higher order.

138. Temperatures Favorable for Nitrification. — The most favorable temperatures for nitrification are between 12° C. (54° F.) and 37° C. (99° F.). It may take place at as low a temperature as 3° or 4° C. (37° and 39° F.); at 50° C. (122° F.) it is feeble, while at 55° C. (130° F.) there is no action.[43] In northern latitudes nitrification is checked during the winter, while in southern latitudes this change takes place during the entire year. Crops which require their nitrogen early in the growing season are frequently placed at a disadvantage because there is less available nitrogen in the soil at that time than later.

139. Strong Sunlight Checks Nitrification.—Nitrification cannot take place in strong sunlight; it prevents the action of all organisms of this class. In fallow land there is no nitrification at the surface but immediately below where the surface soil excludes the sunlight, it is most active. In a cornfield it is more active than in a compacted fallow field.

140. **Base-forming Elements Essential for Nitrification.** — The presence of some base-forming element to combine with the nitric acid produced is a necessary condition for nitrification, and for this purpose calcium carbonate is particularly valuable. The absence of basic materials is one of the frequent causes of non-nitrification. In acid soils, the process is checked for the want of proper basic material. The organisms which carry on the work cannot exist in a strong acid or alkaline solution, consequently in strong acid or alkaline soils the ordinary process cannot take place.[16]

141. **Nitrous Acid Organisms.** — There are at least two nitrifying organisms in the soil: one produces nitrates and the other nitrites or nitrous acid. It is believed that the process takes place in two stages, the first being performed by the nitrous organism, and the process completed by the nitric organism. Warington says that "both organisms are present in the soil in enormous numbers,—and the action of the two organisms proceeds together, as the conditions are favorable to both."

142. **Ammonia-producing Organisms.** — There are also present in the soil organisms which have the power of producing ammonia from proteid bodies. The ammonium compounds produced are acted upon by the nitrifying organisms and readily undergo nitrification.[45]

143. **Denitrification** is just the reverse of the nitri-

fication process, and is the result of the workings of a class of organisms which feed upon the nitrates forming free nitrogen which is liberated as a gas. One of the conditions for denitrification is absence of air, as the organism belongs to the anaerobic class. Denitrification readily takes place in soils saturated with water, and where the soil is compacted so that air is practically excluded.[46]

144. Number and Kinds of Organisms in Soils.—In addition to the micro-organisms which carry on the work of nitrification, denitrification, and ammonification, there are a great many others, some of which are beneficial while others are injurious to crop growth. It has been estimated that in a gram of an average sample of soil there are from 60,000 to 500,000 beneficial and injurious micro-organisms.[47] There are produced from many crop residues, by injurious ferments, chemical products which may be destructive to crop growth. Flax straw for example when it decays in the soil forms products which are destructive to a succeeding flax crop.

A moist soil, rich in organic matter, and containing various salts, may form the medium for the propagation of all classes of organisms. Sewage-sick soils, clover-sick soils, and flax-diseased lands are all the results of bacterial diseases. Many of the organisms which are the cause of such diseases as typhoid fever, cholera, and diphtheria, may propagate and develop in a moist soil under certain conditions, and then find their way through drain waters into surface wells, and cause the spreading of these diseases.

145. Products Formed by Soil Organisms. — In considering the part which micro-organisms take in plant growth, as well as in all similar processes, there are two phases to be considered: (1) the action of the organism itself, and (2) the chemical action of the product of the organism. In the case of nitrification, the action of the organism brings about a change in the composition of the organic matter, producing nitric acid which is merely a product formed as a result of the action of the organism. The nitric acid then acts upon the soil producing nitrates. In the case of soils rich in organic matter, the fermentation changes which take place during humification result in the production of acid products. This is simply the result of the action of the ferments. The acids then act upon the soil bases and produce humates or organic salts. In many fermentation changes there is first the production of some chemical compound, and then the action of this compound upon other bodies. In rendering plant food available, as in nitrification and humification, it is the final product, and not the first product of the organism, which is of value.

146. Inocculating Soils with Organisms. — In growing leguminous crops on soils where they have never before been produced, it has been proposed to supply the essential organisms which assist the crops to obtain their nitrogen. For example, if clover is grown on new land, the soil is liable to be deficient in the organisms which assist in the assimilation of nitrogen and which are present in the root nodules of the plant. If these organisms are supplied, better conditions for growth exist. The extent to which it is necessary to inoculate soils with organisms for the assimilation of nitrogen, has not yet been determined by actual field experiments.

147. Loss of Nitrogen by Fallowing Rich Lands.—Summer fallowing creates conditions favorable to nitrification. A fallow is beneficial to a succeeding crop because of the nitrogen which is rendered available. If a soil is rich in nitrogen and lime, summer fallowing causes the production of more nitrates than can be retained in the soil. The crop utilizes only a part of the nitrogen rendered available, the rest being lost by drainage, ammonification, and denitrification. Hence the available nitrogen is increased while the total nitrogen is greatly decreased.[17]

	Soil before fallowing.	Soil after fallowing.
Total nitrogen	0.154	0.142
Soluble nitrogen	0.002	0.004

The gain of 0.002 per cent. of soluble nitrogen was accompanied by a loss of 0.012 per cent. of total nitrogen. For every pound of available nitrogen there was a loss of 6 pounds.

148. Deep and Shallow Plowing and Nitrification. — In a rich prairie soil nitrification goes on very rapidly. This is one reason why shallow plowing on new breaking gives better results than deep plowing. Deep plowing at first causes nitrification to take place to such an extent that the crop is overstimulated in growth. Deep plowing and thorough cultivation aid nitrification. The longer a soil has been cultivated, the deeper and more thorough must be the cultivation.

149. Spring and Fall Plowing, and Nitrification. — Early fall plowing leaves more available nitrogen at the disposal of the crop than late fall plowing. Nitrification takes place only near the surface. Hence when late spring plowing is practiced there is brought to the surface raw nitrogen, while the available nitrogen has been plowed under, and is beyond the reach of the young plants when they require the most help in obtaining food. The various methods of cultivation as deep and shallow plowing, spring and fall plowing, and surface cultivation have as much influence upon the available nitrogen supply of crops as upon the water supply. The saying that cultivation makes plant food available is particularly true of the element nitrogen, the supply of which is capable of being increased or decreased to a greater extent than that of any other element.

150. Sources of Nitrogenous Manures. — The materials used for enriching soils with nitrogen, to promote crop growth, may be divided into three classes: (1) organic nitrogenous manures, (2) nitrates, and (3) ammonium salts. Each of these classes has a different value as plant food. In fact there are marked differences in fertilizer value between materials belonging to the same class. The nitrogenous organic materials used for fertilizing purposes are: dried blood, tankage, meat scraps and flesh meal, fish offal, cottonseed meal, and leguminous crops as clover and peas. The nitrogen in these substances is principally in the form of protein. When peat and muck are properly used they may also be classed among the nitrogenous manures.

151. Dried Blood. — This is obtained by drying the blood and débris from slaughter-houses. Frequently small amounts of salt and slaked lime are mixed with the blood. It is richest in nitrogen of any of the organic manures. When thoroughly dry it may contain 14 per cent. of nitrogen. As usually sold, it contains from 10 to 20 per cent. of water, and has a nitrogen content of from 9 to 13. Dried blood contains only small amounts of other fertilizer elements. It is strictly a nitrogenous fertilizer, readily yielding to the action of micro-organisms and to nitrification; on account of its fermentable nature, it is a quick-acting fertilizer, and is one of the most valuable of the organic materials used as manure. Dried blood may be applied as a top dressing on grass land. It gives the best returns when used on an impoverished soil to aid crops in the early stages of growth, before the inert nitrogen of the soil becomes available. It is also an excellent form of fertilizer to use on many garden crops, but it should not be placed in direct contact with seeds, as it will cause rotting, nor should it be used in too large amounts. Three hundred pounds per acre is as much as should be applied at one time. When too much is used losses of nitrogen may occur by leaching and by denitrification. It is best applied directly to the soil, as a top dressing in the case of grass, or near the seeds of garden crops, and not mixed with unslaked lime or wood ashes, but each should be used separately. As all plants take up their nitrogen early in their growth, nitrogenous fertilizers as blood should be applied before seeding or soon after. An application of dried blood to partially matured garden crops will cause a prolonged growth and very late maturity.

Storer gives the following directions for preserving any dried blood produced upon farms.[21] "The blood is thoroughly mixed in a shallow box with 4 or 5 times its weight of slaked lime. The mixture is covered with a thin layer of lime and left to dry out. It will keep if stored in a cool place, and may be applied directly to the land or added to a compost heap."

The price per pound of nitrogen in the form of dried blood can be determined from the cost and the analysis of the material. A sample containing 9 per cent. of nitrogen and selling for $20 per ton is equivalent to 11.11 cents per pound for the nitrogen ($2000 \times 0.09 = 180$. $\$20.00 \div 180 = 11.11$ cents).

152. Tankage is composed of miscellaneous refuse matter as bones, trimmings of hides, hair, horns, hoofs, and some blood. The fat and gelatin are, as a rule, first removed by subjecting the material to superheated steam. This miscellaneous refuse, after drying, is ground and sometimes mixed with a little slaked lime to prevent rapid fermentation.

Tankage contains less nitrogen but more phosphoric acid than dried blood. Owing to its miscellaneous nature, it is quite variable in composition, as the following analyses of tankage from the same abattoir at different times show.[13]

	First year.	Second year.	Third year.
Moisture	10.5	9.8	10.9
Nitrogen	5.7	7.6	6.4
Phosphoric acid	12.2	10.6	11.7

As a general rule, tankage contains from 5 to 8 per cent. of nitrogen and from 6 to 14 per cent. of phosphoric acid. It is much slower in its action than dried blood, and supplies the crop with both nitrogen and phosphoric acid. Tankage is a valuable form of fertilizer to use for garden purposes. It may also be used as a top dressing on grass lands, and may be spread broadcast on grain lands. It is best to apply the tankage, when possible, a few days prior to seeding, and it should not come in contact with seeds. Two hundred and fifty pounds per acre is a safe dressing, and when there is sufficient rain to ferment the tankage, 400 pounds per acre may be used. A dressing of 800 pounds in a dry season would be destructive to vegetation. On impoverished soil more may be used than on soils which are for various reasons out of condition. The cost of the nitrogen, as tankage, may be determined from the composition and selling price. If tankage containing 7 per cent. of nitrogen and 12 per cent. of phosphoric acid is selling for $22 per ton, what is the cost of the nitrogen per pound? The market value of phosphoric acid, in the form of bones, should first be ascertained. Suppose that bone phosphoric acid is selling for 4 cents per pound. The phosphoric acid in the ton of tankage would then be worth $9.60, making the nitrogen cost $12.40. The 140 pounds of nitrogen in the ton of fertilizer would then be worth $12.40, or 8.8 cents per pound. In eastern markets the price of tankage is usually much higher than near the large packing houses of the west.

153. Flesh Meal. — The flesh refuse from slaughter-houses is sometimes kept separate from the tankage and sold as flesh meal, the fat and gelatin being first removed and used for the manufacture of glue and soap. Flesh meal is variable in composition and may be very slow in decomposing. It contains from 4 to 8 per cent. or more of nitrogen with an appreciable amount of phosphoric acid. Occasionally it is used for feeding poultry and hogs, and cattle to a limited extent. When thus used the fertilizer value of the dung is nearly equivalent to the original value of the meal.

154. Fish Scrap. — The flesh of fish is very rich in nitrogen.[48] The offal parts, as heads, fins, tails, and intestines, are dried and prepared as a fertilizer. Many species of fish which are not edible are caught in large numbers to be used for this purpose. In sea-coast regions fish fertilizer is one of the cheapest and best of the nitrogenous manures. It is richer in nitrogen than tankage or flesh meal, and in many cases equal to dried blood. It readily undergoes nitrification and is a quick-acting fertilizer.

155. Seed Residues. — Many seeds, as cottonseed and flaxseed, are exceedingly rich in nitrogen. When the oil has been removed, the flaxseed and cottonseed cake are proportionally richer in nitrogen than the original seed. This cake is usually sold as cattle food, but occasionally used as fertilizer. Cottonseed cake contains from 6 to 7 per cent. of nitrogen, and compares fairly well in nitrogen content with animal bodies. Cottonseed cake or meal is not so quick-acting a fertilizer as dried blood, but when used in southern latitudes a little time before seeding, the nitrogen becomes available for crop purposes. Cottonseed or linseed meal containing a high per cent. of oil is much slower in decomposing than that which contains but little oil. It is generally considered better economy to feed the cake to stock and use the manure than to apply the cake directly to the land. Of late years cottonseed-meal has been so reduced in price that its use as a fertilizer has been admissible.

A ton of cottonseed-meal costing $20 and containing 2 per cent. of phosphoric acid and 7 per cent. of nitrogen would be equivalent to buying the nitrogen at 13.1 cents per pound, which is frequently cheaper than purchasing some other nitrogen fertilizer.

156. Leather, Wool Waste and Hair are rich in nitrogen, but on account of their slow rate of decomposing are unsuitable for fertilizer purposes. When present in fertilizers they give poor field results.

157. Solubility of Organic Nitrogenous Materials. — The method employed to detect, in fertilizers, the presence of inert forms of nitrogen as leather, is to digest the material in prepared pepsin solution.[49] Substances like dried blood are nearly all soluble in the pepsin, while leather and inert forms are only partially so. The solubility of organic nitrogen in pepsin solution determines, to a great extent, the value of the material as a fertilizer.[50]

	Soluble in prepared pepsin solution. Per cent. of nitrogen.
Dried blood	94.2
Ground dried fish	75.7
Tankage	73.6
Cottonseed meal	86.4
Hoof and horn meal	30.0
Leather	16.7

158. Peat and Muck. — Many samples of peat and muck are quite rich in nitrogen. The nitrogen is, however, in a very insoluble form, and is with difficulty nitrified. When mixed with stable manure, particularly liquid manure, with the addition of a little lime, fermentation may be induced, and a valuable manure produced. Muck or peat should be dried and sun-cured, and then used as an absorbent in stables. Peat differs from muck in being fibrous. If the muck gives an acid reaction, lime (not quicklime) should be used with it in the stable, as directed under farm manures. When easily obtained muck is one of the cheapest forms of nitrogen.

Composition of Muck Samples.[16]

	Nitrogen. Per cent.
Marshy place, producing hay	2.21
Marshy place, dry in late summer	2.01
Old lake bottom	1.81

159. Leguminous Crops as Nitrogenous Manures. — The frequent use of leguminous crops for manurial purposes is the cheapest way of obtaining nitrogen. When the crop is not removed from the land but is plowed under while green, the practice is called green manuring. This does not enrich the land with any mineral material but results in changing to humate forms inert plant food. Green manuring should take the place of bare fallow, as its effects are in many respects more beneficial. With green manuring, nitrogen is added to the soil while with bare fallow there is a loss of nitrogen. Leguminous crops, as clover, peas, crimson clover, and cow peas, should be made to serve as the main source of the nitrogen for crop production.

160. Sodium Nitrate. — The nitric nitrogen most frequently met with in commercial forms is sodium nitrate, commonly known as Chili saltpeter. It is a natural deposit found extensively in Chili, Peru, and the United States of Colombia. Various theories have been proposed to account for these deposits, but it is difficult to determine just how they have been formed.[10] Their value to agriculture may be estimated from the fact that there are annually used in the United States about 100,000 tons, and in Europe about 700,000 tons. The commercial value of nitrogen in fertilizers is regulated by the price of sodium nitrate which, when pure, contains 16.49 per cent. of nitrogen. Commercial sodium nitrate is from 95 to 97 per cent. pure. An ordinary sample contains about 16 per cent. of nitrogen and costs from $50 to $60 per ton, making the nitrogen worth from 15 to 18 cents per pound.

Sodium nitrate is the most active of all the nitrogenous manures. It is soluble and does not have to undergo the nitrification process before being utilized by crops. On account of its extreme solubility it should be applied sparingly, for it cannot be retained in the soil. As a top dressing on grass, it will respond by imparting a rich green color. It may be used at the rate of 250 pounds per acre, but a much lighter application will generally be found more economical. Sodium nitrate may contain traces of sodium perchlorate, which is destructive to vegetation, if the fertilizer is used in excess.[51] Sodium nitrate, in small amounts, is the fertilizer most frequently resorted to when the forcing of crops is desired as in early market gardening. Its use for fertilizing horticultural crops has become equally as extensive as for general farm crops. Excessive amounts of sodium nitrate may produce injurious results. It stimulates a rank growth of dark green foliage, and retards the maturity of plants, but when properly used it is one of the most valuable of the nitrogenous fertilizers.

161. Ammonium Salts. — Ammonium sulphate is obtained as a by-product in the manufacture of illuminating gas and is extensively sold as a fertilizer. It usually contains about 20 per cent. of nitrogen, equivalent to 95 per cent. of ammonium sulphate, the remaining 5 per cent. being moisture and impurities. Ammonium sulphate is not generally considered the equivalent of sodium nitrate. It is, however, a valuable form of nitrogen. The statements made regarding the use of sodium nitrate apply equally well to the use of ammonium sulphate. Ammonium chloride and ammonium carbonate are not suitable for fertilizers on account of their destructive action upon vegetation.

162. **Nitrogen and Ammonia Equivalent of Fertilizers.** — Nitrogenous fertilizers are sometimes represented as containing a certain amount of ammonia instead of nitrogen; this is so that a higher percentage may be made to appear. Fourteen-seventeenths of ammonia is nitrogen, and if a fertilizer is said to contain 2.25 per cent. ammonia, it is equivalent to 1.85 per cent. of nitrogen.

163. **Purchasing Nitrogenous Manures.** — In purchasing nitrogenous manure, the special purpose for which it is to be used should always be considered. Under some conditions, as forcing a crop on an impoverished soil, sodium nitrate is desirable. Under other conditions tankage, cottonseed cake, or some other form of nitrogen may be made to answer the purpose. There is annually expended in purchasing nitrogenous fertilizers a large amount of money which could be expended more economically, if the science of fertilizing were given a more careful study.

CHAPTER V

FIXATION

164. Fixation, a Chemical Change.—When a fertilizer is applied to a soil chemical changes take place between the soil and the fertilizer. There is a general tendency for the soluble matter of fertilizers to undergo chemical changes and become insoluble. This process is known as fixation. If a solution of potassium chloride be percolated through a column of clay, the filtrate will contain scarcely a trace of potassium chloride, but instead calcium and other chlorides. In its action upon the soil, the potassium chloride has undergone a chemical change, the element potassium being replaced by the element calcium. An exchange has taken place between the two bases.

165. Fixation Due to Zeolites. — It has been shown by experiments, particularly by Way and Voechler, that fixation is due mainly to the zeolitic silicates.[52] Sandy soils containing but little clay have only a feeble power of fixation. Clay soils when digested with hydrochloric acid to remove the zeolitic silicates, lose their power of fixation. The fixation of potassium chloride and the liberation of calcium chloride may be illustrated by the following reaction :

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ Fe_2O_3 \\ \text{etc.} \end{matrix}\right\}_x.(SiO_2)_x.H_2O + 2HCl = \left.\begin{matrix} Al_2O_3 \\ K_2O \\ Fe_2O_3 \\ \text{etc.} \end{matrix}\right\}_x(SiO_2)_x.H_2O + CaCl_2.$$

166. Humus May Cause Fixation. — Other compounds of the soil as humus and calcium carbonate may also take an important part in fixation. In the case of humus a union takes place between the basic material and the organic matter of the soil.

167. Soils Possess Different Powers of Fixation. — All soils do not possess the power of fixation to the same extent. Heavy clays have the greatest fixative power while sandy soils have the least. Experiments have shown that in the first nine inches of soil from 2,000 to 8,000 pounds per acre of potash and phosphoric acid may undergo fixation.[53] Hence it is that a fertilizer, after being applied to a soil, may be entirely changed in composition, so that the plant feeds on the chemical compounds formed, rather than on the original fertilizer.

168. Nitrates Cannot Undergo Fixation. — Nitrogen in the form of nitrates or nitrites cannot undergo fixation. This is because all of the ordinary forms of nitrates are soluble. If potassium nitrate be added to a soil, calcium nitrate will doubtless be obtained as the soluble compound. The potassium undergoes fixation, but the nitrate radical does not. Chlorides are likewise incapable of undergoing fixation.

169. Fixation May Make Plant Food Less Available. — If a liberal dressing of phosphate fertilizer be applied to a heavy clay soil, the phosphoric acid which is not utilized the first year or two may undergo fixation to such an extent as to become unavailable as plant food. It is not desirable to apply heavy dressings of fertilizers at long intervals because of fixation. It is always best to make lighter applications and more frequently.

170. Fixation, a Desirable Property of Soils.— If it were not for the process of fixation, soils in regions of heavy rains would soon become sterile. On account of the plant food being rendered insoluble, it is retained in the soil. The plant food which undergoes fixation is, as a rule, in an available condition, unless the soil be one of unusual composition. The fixation of fertilizers regulates the supply of crop food. Many fertilizers, if they did not undergo this process, would be injurious to crops. There would be an abnormal amount of soluble alkaline or acid compounds which would be destructive. The process of fixation first taking place removes, to a great extent, the water-soluble salts, particularly when the reaction is one of union rather than replacement. Then the plant is free to render soluble its own plant food in quantities and at times desired.

Farm manures and commercial fertilizers alike undergo the process of fixation and, in studying fertilizers, their action upon the soil and the products of fixation are matters of prime importance.

CHAPTER VI

FARM MANURE

171. Variable Composition of Farm Manures. — The term 'farm manure' does not designate a product of definite composition. Manure is the most variable in chemical composition of any of the materials produced on the farm. It may contain a large amount of straw, in which case it is called coarse manure; or it may contain only the solid excrements and a little straw, the liquid excrements being lost by leaching; then again it may consist of the droppings of poorly fed animals, or of the mixed excrements of different classes of well-fed animals.

The term 'stable manure' has been proposed for that product which contains all of the solid and liquid excrements with the necessary absorbent, before any losses have been sustained.[15] The term 'barnyard manure' is restricted to that material which accumulates around some barns and farm yards, and is exposed to leaching rains and the drying action of the sun.

172. Average Composition of Manures. — The solid excrements of animals contain from 60 to 85 per cent. of water; when mixed with straw, and the liquid excrements are retained, the mixed manure contains about 75 per cent. of water. The nitrogen varies from 0.4 to 0.9 per cent., according to the nature of the food and the extent to which other factors have affected the composition. In general, animals consuming liberal amounts of coarse fodders produce manure

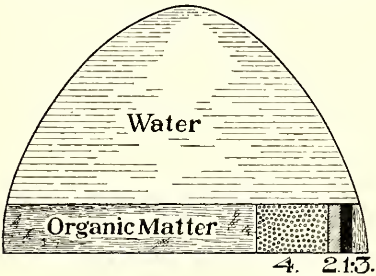


Fig. 24. Average composition of fresh manure.
1. Nitrogen. 2. Phosphoric acid. 3. Potash.

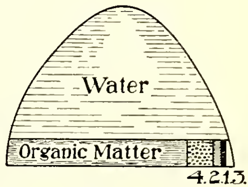


Fig. 25. Manure after six months' exposure.

with a higher per cent. of potash than of phosphoric acid. This is because the potash in the food exceeds the phosphoric acid. The average composition of mixed stable manure is about as follows:

	Average. Per cent.	Range. Per cent.
Nitrogen	0.50	0.4 to 0.8
Phosphoric acid	0.35	0.2 to 0.5
Potash	0.50	0.3 to 0.9

In calculating the amount of fertility in manures, it is more satisfactory to compute the value from the food consumed and the care which the manure has received, than to use figures expressing average composition.

173. Factors which Influence the Composition and Value of Manure. —

I. Kind and amount of absorbents used.

II. Kind and amount of food consumed.

III. Age and kind of animals.

IV. Methods employed in collecting, preserving and utilizing the manure.

Any one of the above, as well as many minor factors, may influence the composition and value of stable manure.

174. Absorbents. — The most universal absorbent is straw. Wheat straw and barley straw have about the same manurial value. Oat straw, however, is more valuable. The average composition of straw and other absorbents is as follows:

	Straw. Per cent.	Leaves. Per cent.	Peat. Per cent.	Sawdust. Per cent.
Nitrogen	0.40	0.6	1.0	0.1
Phosphoric acid	0.36	0.3	..	0.2
Potash	0.80	0.3	..	0.4

When a large amount of straw is used the per cent. of nitrogen and phosphoric acid is decreased, while the per cent. of potash is slightly increased. Sawdust and leaves both make the manure more dilute. Dry peat makes the manure richer in nitrogen. The absorbent powers of these different materials are about as follows:[13]

	Per cent. of water absorbed.
Fine cut straw	30.0
Coarse uncut straw	18.0
Peat	60.0
Sawdust	45.0

The proportion of absorbents in manure ranges from a fifth to a third of the total weight of the manure.

175. Use of Peat and Muck as Absorbents. — On account of the high per cent. of nitrogen in peat and the power which it possesses when dry of absorbing water, it is a valuable material to use as an absorbent in stables. As previously explained, peat is slow of decomposition, but when mixed with the liquid manure it readily yields to fermentation, particularly if a little land plaster or marl be used in the stable along with the peat. Peat has a high absorptive power for gases as well as liquids, and when used stables are rendered particularly free from foul odors.

RELATION OF FOOD CONSUMED TO MANURE PRODUCED

176. Bulky and Concentrated Foods. — The more concentrated and digestible the food consumed, the more valuable is the manure. Coarse bulky fodders always give a large amount of a poor quality of manure. For example, the manure from animals fed on timothy hay and that from animals fed on clover hay and grain, show a wide difference in composition. The dry matter of timothy hay is about 55 per cent. digestible. From a ton of timothy hay there will be about 792 pounds of dry matter in the manure. The nitrogen, phosphoric acid, and potash in the food consumed are nearly all returned in the manure, except under those conditions which will be noted. The manure from a ton of mixed feed, as clover and bran, will be smaller in amount but more concentrated than that produced from timothy. In a ton of timothy and in a ton of mixed feed (1500 lbs. clover, 500 lbs. bran) there are present:

	Timothy. Lbs.	Mixed feed. Lbs.
Nitrogen	25.0	40.0
Phosphoric acid	9.0	24.0
Potash	40.0	30.0

The nitrogen, phosphoric acid, and potash in these two rations are retained in the animal bodies in dissimilar amounts; that is, 10 per cent. more of these elements are retained from the more liberal ration, due to more favorable conditions for growth. Making allowance for this fact there will be present in the manure from the mixed feed one-half more nitrogen, and two and one-half times as much phosphoric acid, as in the manure from the timothy hay, which, free from bedding, contains about 792 pounds of indigestible matter while that from the mixed feed contains 760 pounds, the mixed ration being more digestible. If both manures contain the same amount of absorbents, the manure from the ton of mixed clover and bran will weigh slightly less, but contain more fertility than that from the timothy hay.

The value of the manure can be approximately determined from the composition of the food consumed. Only a small amount of the nitrogen in the food is retained in the body. The larger portion is used for repair purposes. The nitrogen of the tissues which have been renewed is voided as urea in the liquid excrements. Some of the nitrogenous compounds of the food are utilized for the production of fat, in which case the nitrogen is voided in the excrements. The fact that but little of the nitrogen of the food, under most conditions, is retained in the body may be observed from the figures of Lawes and Gilbert relating to the composition of the flesh added to animals while undergoing the fattening process.[54]

INCREASE DURING FATTENING.

	Water.	Dry matter.	Fat.	Nitrogenous matter.	Ash.
Ox	24.6	75.4	66.2	7.69	1.47
Sheep......	20.1	79.9	70.4	7.13	2.36
Pigs	22.0	78.0	71.5	6.44	0.06

The results of numerous digestion experiments show that when the food undergoes digestion from 5 to 15 per cent. of the nitrogen is, as a rule, retained in the body. The nitrogen of the food is utilized largely to replace that which has been required for vital functions. The nitrogen of the food enters the body, undergoes digestion changes, is utilized for some vital function, and is then voided in the excrements.

The digestion of the food has been compared to the combustion of fuel: the undigested products of the solid excrements represent the ashes, and the urine represents the volatile products. When wood is burned the nitrogen is converted into volatile products. When food is digested and utilized by the body the digestible nitrogen is mainly converted into urea, while the undigestible nitrogen is voided in the dung.

177. Composition of Solid and Liquid Excrements Compared. — In composition the liquid excrements differ from the solids in having a much larger amount of nitrogen and less phosphoric acid.[55]

	Water.		Nitrogen.		Phosphoric acid.		Potash.
	Solids. Per cent.	Liquids. Per cent.	Solids. Per cent.	Liquids. Per cent.	Solids. Per cent.	Liquids. Per cent.	Solids. Per cent.
Cows ..	76	89	0.50	1.20	0.35	...	0.30
Horses.	84	92	0.30	0.86	0.25	...	0.10
Pigs ...	80	97.0	0.60	0.80	0.45	0.12	0.50
Sheep .	58	86.5	0.75	1.40	0.60	0.05	0.30

The nitrogen of the food consumed influences the amount of water in the manure. As a rule, a highly concentrated nitrogenous ration, produces a higher per cent. of water in the manure than a well-balanced ration. There is but little phosphoric acid in the liquid excrements of horses and cows, while the urine of sheep and swine contains appreciable amounts of this element.

The liquid manure is more constant both in composition and amount than the solid excrements. This fact may be observed from the following table, which gives the composition of the solid and liquid excre-

		Solid excrements.			Liquid excrements.		
		Amount.	Nitrogen.	Phosphoric acid.	Amount.	Nitrogen.	Phosphoric acid.
Lbs.	Kind of food daily.	Lbs.	Per cent.	Per cent.	Lbs.	Per cent.	Per cent.
$9\frac{5}{7}$	Barley and shorts	8	0.57	0.72	4	2.05	0.06
6	Barley	4	0.43	0.70	4	2.06	0.16
$5\frac{1}{2}$	Corn and shorts	$2\frac{1}{2}$	0.80	...	4	2.65	0.20
$6\frac{1}{2}$	Corn	$1\frac{5}{7}$	0.82	0.89	4	2.05	0.29

ments from hogs when fed on different amounts of grain.[56]

The amount of waste matter in the urine is nearly the same whether an animal be gaining or losing in flesh, consequently the urine is more constant in both composition and quantity than the solid excrements.

The amount and composition of the solid excrements vary with the amount and kind of food consumed. If the food is indigestible the solid excrements contain a larger part of the nitrogen as indigestible protein. When the body is properly supplied with food for all purposes, normal conditions exist, and the amount of nitrogen voided in the liquid and solid excrements is no more than that supplied in the food consumed.

178. Manurial Value of Foods. — The manurial value of fodder is determined by the amount of nitrogen, phosphoric acid, and potash present in the material. Timothy hay, for example, has a manurial value of $5.30 per ton, which means that if the nitrogen, phosphoric acid, and potash in the timothy hay were purchased in commercial forms they would cost $5.30. Lawes and Gilbert estimate that 80 per cent. of the fertility in fodders is, as a rule, returned in the manure.

In the following table are given the pounds of nitrogen, phosphoric acid, and potash per ton of material:[57]

	Nitrogen. Lbs.	Phosphoric acid. Lbs.	Potash. Lbs.
Timothy hay	25	9	40
Clover hay	45	14	30
Wheat straw	11	4	12
Oat straw	12	4	18
Wheat	45	20	12
Oats	33	16	11
Barley	40	18	11
Rye	42	20	13
Flax	87	32	14
Corn	32	14	8
Wheat Shorts	48	31	20
Wheat Bran	54	52	30
Oil meal	100	35	25
Cottonseed meal	130	35	56
Milk	10	3	3
Cheese	90	23	5
Live cattle	53	37	3
Potatoes	7	3	11
Butter	1	1	1
Live pigs	40	17	3

179. Commercial Value of Manures. — When the value of farm manure is calculated on the same basis as that of commercial fertilizers it will be found that stable manure is worth from $2 to $3.50 per ton. The value of the increased crop resulting from the use of manure will vary with conditions. It is sometimes stated that the phosphoric acid and potash in stable manures is not as soluble as that in commercial fertilizers, and consequently it is worth less. While not so soluble in the form of manure, it frequently happens that the phosphoric acid and potash in the commercial fertilizers become, through fixation processes, less soluble when mixed with the soil than the same elements in stable manure.

Stable manure is valuable not only for the fertility contained but also because it makes the inert plant food of the soil more available and exercises such a favorable influence on the water supply of crops; hence it is justifiable to assign the same value to the elements in well-prepared farm manures as to those in commercial fertilizers.

If well-prepared stable manure is not worth $2.50 per ton, then too much, accordingly, is paid for commercial forms of plant food.

INFLUENCE OF AGE AND KIND OF ANIMAL

180. Manure from Young and Mature Animals. — The manure from older animals is more valuable than that from young animals, even when fed the same kind of food. This is because more of the phosphoric acid and nitrogenous matters are retained in the body of a young animal. It is not so much a difference in digestive power as a difference in retentive power. In older animals the proportion of new nitrogenous tissue produced is much less than in young animals, and more of the nitrogen of the food is used for repair purposes and subsequently voided in the manure, while with younger animals more of the nitrogen of the food is retained for the construction of new muscular tissue.

The difference in composition between the manure of old and of young animals is not, however, so great as might appear.

When an animal is neither gaining nor losing in flesh, and is not producing milk, an equilibrium is established between the nitrogen in the food supply and the nitrogen in the manure. Under such conditions practically all of the nitrogen of the food is returned in the manure.[56]

181. Cow Manure. — A milch cow when fed a balanced ration, will make from 60 to 70 pounds of solid and liquid manure a day, of which 20 to 30 pounds are liquid excrements. The solid excrements contain about 6 pounds of dry matter. When a cow is fed clover hay, corn fodder, and grain, about half of the nitrogen of the food is in the urine, about one-fourth in the milk, and the remainder in the solid excrements. Hence, if the solid excrements only are collected, but a quarter of the nitrogen of the food is obtained, while if both solids and liquids are utilized three-quarters of the nitrogen is secured. Cow manure is extremely variable in composition, and is the most bulky of any manure produced by domestic animals. A well-fed cow will produce about 80 lbs. of manure per day, including absorbents.

182. Horse Manure. — Horse manure contains less water than cow manure, and is of a more fibrous nature, doubtless due to the horse possessing less power for digesting cellulose materials. Horse manure readily ferments and gives off ammonia products. When the manure becomes dry, fire-fanging results, due to rapid fermentation followed by the growth of fungus bodies. Horse manure is generally considered of but little value. This is because it so readily deteriorates in value and when used it has frequently lost much of its nitrogen by fermentation. When mixed with cow manure, both manures are improved, the rapid fermentation of the horse manure is checked, and at the same time the cow manure is improved in texture. It is estimated that horses void about three-fifths of their manure in the stable. A well-fed horse at ordinarily hard work will produce about 50 pounds of manure per day, of which about one-fourth is urine. A horse will produce about 6 tons of manure per year in the stable. If properly preserved and used it is a valuable, quick-acting manure, but if allowed to ferment and leach it will give poor results.

183. Sheep Manure. — Sheep produce a small amount of concentrated manure, containing less water than that produced by any other domestic animal. It readily ferments and is a quick-acting fertilizer. When mixed with horse and cow manure the mixture ferments more evenly. Because of the small amount of water, sheep manure is very concentrated in composition. It is valuable for general gardening purposes, or whenever a concentrated quick-acting manure is desired.

184. Hog Manure. — The composition of hog manure is exceedingly variable on account of the varied character of the food consumed. The manure from fattening hogs which are well fed compares very favorably in composition and value with the manure produced by other animals. It contains a high per cent. of water, and, like cow manure, may be slow in decomposing. From a given weight of grain, pigs produce less dry matter in the manure than sheep or cows. The liquid excrements of well-fed hogs are rich in nitrogen, containing, on an average, about 2 per cent. On account of hog manure containing so much water, losses by leaching readily occur. The solid excrements when leached and deprived of the liquid excrements have but little value as a fertilizer.

185. Hen Manure. — Like all other farm manures hen manure is variable in composition. The nitrogen is present mainly in the form of ammonium compounds. This makes it a quick-acting fertilizer. When fowls are well fed the manure contains about the same amount of nitrogen as sheep manure. Hen manure readily ferments, and if not properly cared for losses of nitrogen, as ammonia, occur. It is not advisable to mix hard wood ashes or ordinary lime with hen manure because the ammonia is so readily liberated by alkaline compounds. The value of hen manure is due to its being a quick-acting fertilizer rather than to its containing such a large amount of fertility. A hen produces about a bushel of manure per year.[55]

COMPOSITION OF HEN MANURE.

	Per cent.
Water	57.50
Nitrogen	1.27
Phosphoric acid	0.82
Potash	0.28

186. Mixing of Solid and Liquid Excrements. — The solid and liquid excrements, when properly mixed, make a well-balanced manure. The urine alone is not a complete manure, as it is deficient in phosphoric acid and other mineral matter. The solid excrements and the urine, when mixed with soil, readily undergo nitrification. The nitrogen in the solid excrements is in the form of indigestible protein, and is rendered available as plant food more slowly. Land which has been heavily dressed with leached manure has received an unbalanced manure, and is deficient in nitrogen but fairly well supplied with mineral matter. Such a soil may fail to respond because of the unbalanced character of the manure.

187. Volatile Products from Manure. — The fermentation of manure in stables may cause the production of a large number of volatile compounds. The ammonia and nitrogen compounds are products which cause losses of value to the manure. Urea, when it ferments, produces ammonia or ammonium carbonate. If ammonia is produced it combines with the carbon dioxide, which is always present in stables in liberal amounts as a product of respiration, and forms ammonium carbonate, a volatile compound. When the stable atmosphere becomes charged with ammonium carbonate, some of it is deposited on the walls of the stable, forming a white coating. The white coating found on harnesses and carriages stored in poorly ventilated stables, is ammonium carbonate. Accumulations of manure in the stable and poor ventilation are the conditions favorable to the production of this compound.

188. Human Excrements. — The use of human excrements as manure is sometimes advised, and in some countries they are extensively used. When fresh, human excrements may contain a high per cent. of nitrogen and phosphoric acid; when fermented, a loss of nitrogen occurs. Heiden estimates that in a year 1,000 pounds of excrements per person are made, which contain $2.25 worth of fertility.[58] For sanitary reasons, human excrements should be used with great care. It is doubtful with the abundance and cheapness of plant food whether their extensive use as manure is advisable. About 1840, Liebig feared that the essential elements of plant food would accumulate in the vicinity of large cities and be wasted, and that in time there would be a decline in fertility due to this cause.[59] Many political economists shared the same fear. Since that time the fixation of atmospheric nitrogen through the agency of leguminous crops, the extensive beds of sodium nitrate, phosphate rock, and Stasfurt salts, have been discovered, and larger areas of more fertile soil have been brought under cultivation, so that it is not now considered so essential to devise means for utilizing human excrements as manure.

THE PRESERVATION OF MANURE

189. Leaching. — Leaching of manure is the greatest source of loss. Experiments by Roberts have shown that when horse manure is thrown in a loose pile and subjected to the joint action of leaching and weathering it may lose nearly 60 per cent. of its most valuable fertilizing constituents in six months. The tabular results are as follows:[15]

	April 25. Lbs.	Sept. 28. Lbs.	Loss. Per cent.
Gross weight	4,000	1,730	57
Nitrogen	19.60	7.79	60
Phosphoric acid	14.80	7.79	47
Potash	36.0	8.65	76
Value per ton	$2.80	$1.06	

Cow manure, on account of its more compact nature, does not leach so readily as horse manure. A similar experiment with cow manure, conducted at the same time, showed the following losses:

	April 25. Lbs.	Sept. 28. Lbs.	Loss. Per cent.
Gross weight	10,000	5,125	49
Nitrogen	47	28	41
Phosphoric acid	32	26	19
Potash	48	44	8
Value per ton	$2.29	$1.60	

When mixed cow and horse manure was compacted and "placed in a galvanized iron pan with a perforated bottom" for six months, the losses were as follows:

	March 29. Lbs.	Sept. 30. Lbs.	Loss. Per cent.
Gross weight	226	222	..
Nitrogen	1.04	1.01	3.2
Phosphoric acid	0.61	0.58	4.7
Potash	1.20	0.43	35.0
Value per ton	$2.38	$2.16	

190. Losses by Fermentation. — When rapid fermentation takes place in manure, appreciable losses of nitrogen may occur. When the manure is well compacted and the pile is so constructed as to prevent the rapid circulation of air through the pile, the losses are reduced to the minimum. Experiments have shown that when leaching is prevented, the losses of nitrogen by the fermentation of mixed manure are very small. Under unfavorable conditions the losses by fermentation may exceed 15 per cent. Hen manure, sheep manure, and horse manure suffer the greatest losses by rapid fermentation. When extreme conditions follow each other in succession, as excessive moisture, drought, and high temperature, then the greatest losses occur.

191. Different Kinds of Fermentation. — The large number of organisms present in manure all belong to one of two classes: (1) aerobic, or (2) anaerobic. The aerobic ferments require an abundant supply of air in order to carry on their work. When deprived of oxygen they become inactive. The anaerobic ferments require the opposite conditions. They become inactive in the presence of oxygen and can thrive only when air is excluded. In the center of a well-constructed manure pile anaerobic fermentation takes

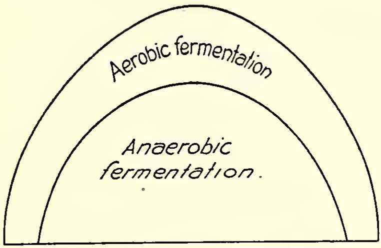


Fig. 26. Fermentation of Manure.

place while on the surface aerobic fermentation is active. The anaerobic ferments prepare the way for the action of the aerobic bodies. When aerobic fermentation is completed the organic matter is converted into water, carbon dioxide, ammonia, and allied gases. From what has been said regarding the action of these two classes of ferments it is evident that anaerobic fermentation is the most desirable.

192. **Water Necessary for Fermentation.** — In order to produce the best results in fermenting manure water is necessary. If the manure becomes too dry abnormal fermentation takes place. Water is always beneficial on manure as long as leaching is prevented;

it encourages anaerobic fermentation by excluding the air. Excessive amounts of water, as that which falls on piles from the eaves of buildings, is more than is required for good fermentation. During a dry time it is beneficial, if conditions admit, to water the compost pile.

193. Heat Produced during Fermentation. — During the active fermentation of horse manure and sheep manure, a temperature of 175° F. may be reached by the fermenting mass. Ordinarily, however, the temperature of the manure pile ranges from 110° to 130° F. The highest temperature is reached near the surface where fermentation is most rapid. The temperature of fermentation may be sufficiently high if the manure is mixed with the proper litter to cause spontaneous combustion.

194. Composting Manure May Improve Its Quality. — When manure is composted so that leaching and rapid fermentation do not take place the manure may be improved in quality by becoming more concentrated. Pound for pound, composted manure is more concentrated than fresh manure, because, if properly cared for, nearly all of the nitrogen, phosphoric acid, and potash of the original manure are obtained in a smaller bulk. A ton of composted manure is obtained from about 2,800 pounds of stable manure.

	Fresh manure. Per cent.	Composted manure. Per cent.
Nitrogen	0.50	0.60
Phosphoric acid	0.28	0.39
Potash	0.60	0.80

In composting manure it should be the aim to induce anaerobic fermentation by excluding the air and retaining the water. This can be best accomplished by using mixed manure and making a compact pile, capable of shedding water. The compost pile should be shaded to secure better conditions for fermentation. If the pile becomes offensive a little earth on the surface will absorb the odors.

195. Use of Preservatives. — The use of preservatives as gypsum and kainit have been recommended to prevent fermentation losses. Opinions differ as to their value. Moist gypsum, when it comes in contact with ammonium carbonate, produces ammonium sulphate, a non-volatile compound,

$$(NH_4)_2CO_3 + CaSO_4 = (NH_4)_2SO_4 + CaCO_3.$$

Gypsum is used at the rate of about one-half pound per day for each animal.[58] Experiments have shown that it may prevent a loss of 5 per cent. of the nitrogen of horse manure. It may be safely sprinkled in the stalls as it has no action on the feet of animals. When gypsum is used as a fertilizer it is very desirable to use it in stables. It is not advisable to use lime in any other form than the sulphate. Unslaked lime will decompose manure and liberate ammonia. Neither kainit nor gypsum should be used when manure is exposed to the leaching action of rains. Preservatives cannot be made to take the place of want of care in handling manure; they should be used only when the manure receives the best of care.

196. Manure Produced in Covered Sheds and Box Stalls. — Manure produced under cover as in sheds and box stalls is of superior quality to that produced in any other way. Losses by leaching are avoided, the manure is compacted by the tramping of animals, and the solid and liquid excrements are more evenly mixed with the absorbents. By no other system is there such a large percentage of the fertility recovered. Manure from well-fed cattle, when collected and prepared in a covered shed, will have about the following composition:

	Per cent.
Water	70.00
Nitrogen	0.90
Phosphoric acid	0.60
Potash	0.70

197. Value of Protected Manure. — Manure that is produced under cover has greater crop-producing powers than manure that is cared for in any other way. Experiments by Kinnard show that such manure produced 4 tons more potatoes per acre than pile manure, while 11 bushels more of wheat per acre were obtained from land which had the previous year received the covered manure than from land which received the uncovered manure.[61]

THE USE OF MANURE

198. Direct Hauling to Fields.— It is always desirable, whenever conditions allow, to draw the manure directly to the field and spread it, rather than to allow it to accumulate about barns or in the barnyard. When taken directly to the field from the stable no losses by leaching occur, and the slight loss from fermentation and volatilization of the ammonia are more than compensated for by the benefits derived from the action of the fresh manure upon the soil. When manure undergoes fermentation in the soil, as previously stated it combines with the mineral matter of the soil and produces humates. The practice of hauling the manure directly to the field as soon as produced is the most economical way of caring for it.

With scant rainfall, composting the manure before spreading is necessary, but with a liberal rainfall it is not essential. On a loam soil a direct application of stable manure is more advisable than on heavy clay or light sandy soils. On sandy soils there is frequently an insufficient supply of water to properly ferment the manure. Manure sometimes fails to show any beneficial effects the first year on heavy clay land, because of the slow rate of decomposition, but the second and third years the beneficial effects are noticeable.

199. Coarse Manure May Be Injurious. — The application of coarse leached manure may cause the soil to be so open and porous as to affect the water supply of the crop, by introducing, below the surface soil, a layer of straw, which breaks the capillary connection with the subsoil. Coarse manure and shallow spring plowing are frequently injurious, when fine or well-composted manure and fall plowing are beneficial. The injury resulting from the use of coarse manure is frequently due to its being allowed to leach before it is used, so that it does not properly ferment in the soil.

200. Manuring Pasture Land. — In semiarid regions, where manure decomposes slowly, it is sometimes advisable to spread it upon the pasture land as

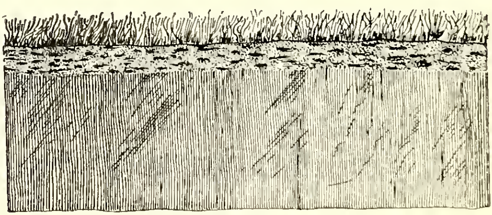


Fig. 27. Manured land.

a top dressing. The manure encourages the growth of grass, which appropriates plant food otherwise lost, and it also acts as a mulch preventing excessive evaporation. Then when the pasture land is plowed and prepared for a grain crop it contains a better store of both water and available plant food. The manuring of pasture lands is one of the best ways of utilizing the

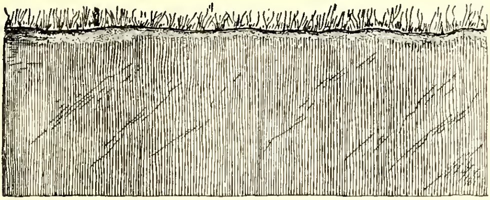


Fig. 28. Unmanured land.

manure when trouble arises from slow decomposition.

201. Small Manure Piles Undesirable. — It is sometimes the custom to make a large number of small manure piles in fields. This is a poor practice, for it entails additional expense in spreading the manure, and the small piles are usually so constructed that heavy losses occur, and the manure, when finally spread, is not uniform in composition. Oats grown on land manured in this way present an uneven appearance. There are small patches of thrifty, overfed oats, corresponding to the places occupied by the former manure piles, while large areas of half-starved oats may be observed.

202. Rate of Application. — The amount of manure that should be applied depends upon the nature of the soil and the crop. On loam soils intended for general truck purposes heavier applications may be made than when grain is raised. For general farm purposes, 10 tons per acre are usually sufficient. It is better economy to make frequent light applications than heavier ones at long intervals. When manure is spread frequently the soil is kept in a more even state of fertility, and losses by percolation, denitrification, and ammonification are prevented.

For growing garden crops 20 tons and more per acre are sometimes used. It is better, however, not to use stable manure too liberally for trucking, but to supplement it with special fertilizers as the crop may require. Soils which contain a large amount of calcium carbonate admit of more frequent and heavier applications of manure than soils which are deficient in this compound. The lime aids fermentation and nitrification.

203. Crops Most Suitable for Manuring.— Soils which contain a low stock of fertility will admit of manuring for the production of almost any crop. Soils well stocked with plant food, like some of the western prairie soils, which are in need of manure mainly for the physical action, will not admit of its direct use on all crops. On a prairie soil of average fertility an application of well-rotted manure will cause wheat to lodge. When it cannot be applied directly to a crop, it may be used indirectly. It never injures corn by causing too rank a growth, and when wheat follows corn which has been manured there is but little danger of loss from lodging.

On some soils stable manure cannot be used for growing sugar-beets; on other soils it does not seem to exercise an injurious effect. Tobacco is injured as to quality by manure. Crops, as flax, tobacco, sugar-beets, and wheat, which do not admit of direct applications of stable manure all require the manuring of preceding crops. When in doubt as to what crop to apply the manure to, it is always safe to apply it to corn, and then to follow with the crop which would have been injured by its direct application.

The fact that coarse, leached manure may cause trouble in a dry season, and that well-rotted manure may cause grain to lodge, are no substantial reasons why manure should be wasted as it frequently is in western farming by being burned, used for making roads, thrown away in streams, or used for filling up low places.

204. Comparative Value of Manure and Crops.— The manure from a given amount of grain or fodder always gives better results than if the food itself were used directly as manure. The manure from a ton of bran will give better returns than if the bran itself were used. This is because so little of the fertilizing elements is extracted in the process of digestion and the action of the digestive fluids upon the food makes the manure more readily available as a fertilizer than the food which has not passed through any of the stages of fermentation. It is better economy to use products as linseed meal and cottonseed meal for feeding stock, and take good care of the manure, than to use the materials directly.

205. Lasting Effects of Manure. — No other manures make themselves felt for so long a time as farm manures. In ordinary farm practice an application of stable manure will visibly affect the crops for a number of years. At the Rothamsted Experiment Station, records have been kept for over fifty years as to the effects of manures upon soils. In one experiment manure was used for twenty years and then discontinued for the same period. It was observed that when its use was discontinued there was a gradual decline in crop-producing power, but not so rapid as on plots where no manure had been used. The manure which had been applied for the twenty-year period prior to its disuse made itself felt for an ensuing period of twenty years.

206. Comparative Value of Manure Produced on Two Farms. — The fact that there is a great difference in the composition and value of manures produced on different farms may be observed from the following examples:

On one farm 10 tons of timothy are fed. The liquid manure is not preserved and 25 per cent. of the remaining fertility is leached out of the solids, while 5 per cent. of the nitrogen is lost by volatilization. It is estimated that half of the nitrogen and potash of the food is voided in the urine. On account of the scant amount and poor quality of the food no milk or flesh is produced.

On another farm 7.5 tons of clover hay and 2.5 tons of bran are fed. The liquid excrements are collected

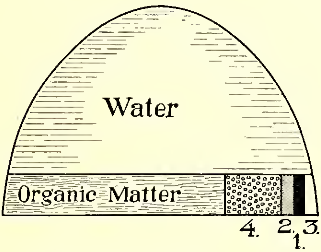


Fig. 29. Good manure.

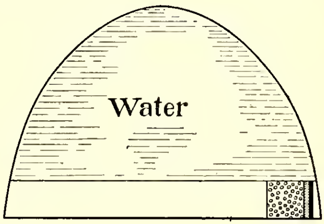


Fig. 30. Poor manure.

and the manure is taken directly to the field and spread. It is estimated that 20 per cent. of the nitrogen and 4 per cent. of the phosphoric acid and potash are utilized for the production of flesh or milk.

The relative value of the manures from the two farms is as follows:

FARM No. 1.

	In 10 tons timothy. Lbs.
Nitrogen	250
Phosphoric acid	90
Potash	400

Loss in urine.

$250 \div 2 = 125$ lbs. nitrogen

$400 \div 2 = 200$ lbs. potash

Loss by leaching.

$125 \times 0.30 = 37.50$ lbs. nitrogen
$90 \times 0.25 = 22.50$ lbs. phosphoric acid
$200 \times 0.25 = 50$ lbs. potash

Total loss.

	Lbs.	Per cent.
Nitrogen	162.5	65
Phosphoric acid	22.5	25
Potash	250.0	62

	Present in final product, manure from 1 ton timothy. Lbs.
Nitrogen	8.75
Phosphoric acid	6.75
Potash	15.00
Relative money value	$1.00

FARM NO. 2.

	In 10 tons mixed feed. Lbs.
Nitrogen	400
Phosphoric acid	240
Potash	300

Loss, sold in milk and retained in body.

	Lbs.	Per cent.
Nitrogen, 400×0.20	80	20
Phosphoric acid, estimated	10	4
Potash	12	4

	Present in final product, manure from 1 ton feed. Lbs.
Nitrogen	32.0
Phosphoric acid	23.0
Potash	26.0
Relative money value	$3.80

207. Summary of Ways in which Stable Manure May Be Beneficial. —

1. By adding new stores of plant food to the soil.

2. By acting upon the soil, forming humates and rendering the inert plant food of the soil more available.

3. By raising the temperature of the soil.

4. By making the soil darker colored.

5. By enabling soils to retain more water and to give it up gradually to growing crops.

6. By improving the physical condition of sandy and clay soils.

7. By preventing the denuding effects of heavy wind storms.

CHAPTER VII

PHOSPHATE FERTILIZERS

208. Importance of Phosphorus as Plant Food.—Phosphorus in the form of phosphates is one of the essential elements of plant food. None of the higher orders of plants can complete their growth unless supplied with this element in some form. The illustration (Fig. 31) shows an oat plant which received no phosphates, but was supplied with all of the other elements of plant food. As soon as the phosphates stored up in the seed had been utilized, the plant ceased to grow, and after a few weeks died of phosphate starvation, having made the total growth shown in the illustration. All crops demand their phosphates at an early stage in their development. Wheat takes up eighty per cent. of its phosphoric acid in the first half of the growing period,[36] while clover has assimilated all of its phosphoric acid by the time the plant reaches full bloom.[42] Phosphates ac-

Fig. 31.
Oat plant grown without phosphorus.

cumulate, to a great extent, in the seeds of all grains and are usually sold from the farm, especially when grain farming is extensively followed. All crops are very sensitive to the absence of phosphates; an imperfect supply results in the production of light weight grains. The nitrogen and the phosphates are to a great extent stored up in the same parts of the plant, particularly in the seed, which is richer in both nitrogen and phosphorus than is any other part. Nitrogen is the chief element of protein, while phosphorus is necessary to aid in transporting the protein compounds through the cell walls of plants. In speaking of the phosphorus in plants and in fertilizers, as well as in soils, the term phosphoric acid or phosphoric anhydride is used. This is because phosphorus is an acid-forming element and, as already explained, the anhydride of the element is always considered instead of the element itself.

209. Amount of Phosphoric Acid Removed in Crops. — The amount of phosphoric acid removed in an acre of different farm crops ranges from 18 to 30 pounds:

	Phosphoric acid per acre. Lbs.
Wheat, 20 bu	12.5
Straw, 2,000 lbs	7.5
Total	20.0

	Phosphoric acid per acre. Lbs.
Barley, 40 bu	15
Straw, 3,000 lbs	5
Total	20
Oats, 50 bu	12
Straw, 3,000 lbs	6
Total	18
Corn, 65 bu	18
Stalks, 4,000 lbs	4
Total	22
Peas, 3,500 lbs	25
Red clover, 4,000 lbs	28
Potatoes, 150 bu	20
Flax, 15 bu	15
Straw, 1,800 lbs	3
Total	18

210. Amount of Phosphoric Acid in Soils. — To meet the demand of growing crops (for 25 pounds of phosphoric acid per acre), there is present in soils from 1,000, and less, to 8,000 pounds of phosphoric acid per acre, of which, however, only a fraction is available as plant food at any one time. The availability of phosphoric acid is a factor which has a great deal to do in determining crop-producing power. Many soils contain a large amount of total phosphoric acid, which has become unavailable because of poor cultivation and the absence of stable manure and lime to combine with the phosphates and render them available.

211. **Source of Phosphoric Acid in Soils.**— The phosphates found in soils are derived mainly from the disintegration of phosphate rock, and from the remains of animal life. The phosphate deposits found in various localities are supposed to have been derived either from the remains of marine animals or from sea-water highly charged with soluble phosphates. These deposits have been subjected to various geological and climatic changes which have resulted in the formation of soft phosphate, pebble phosphate, and rock phosphate.[62]

212. **Commercial Forms of Phosphoric Acid.**— The commercial sources of phosphate fertilizers are (1) phosphate rock, (2) bones and bone preparations, (3) phosphate slag, and (4) guano. With the exception of phosphate slag and guano, the prevailing form of the phosphorus is tricalcium phosphate. Before being used for commercial purposes, the tricalcium phosphate, which is insoluble and unavailable, is treated with sulphuric acid which produces monocalcium phosphate, a soluble and available form of plant food.

$$Ca_3(PO_4)_2 + 2H_2SO_4 + 5H_2O = CaH_4(PO_4)_2 + H_2O + 2CaSO_4.2H_2O.$$

In making phosphate fertilizers from bones or phosphate rock an excess of the rock is used so that there will be no free acid to be injurious to vegetation.

213. Different Forms of Calcium Phosphate.—The usual form in which calcium phosphate is found in nature is tricalcium phosphate, $Ca_3(PO_4)_2$. Unless associated with organic matter or salts which render it soluble it is of but little value as plant food. When tricalcium phosphate is treated with sulphuric acid, monocalcium phosphate, $CaH_4(PO_4)_2$, is formed. This compound is soluble in water and directly available as plant food. When tricalcium and monocalcium phosphate are brought together in a moist condition, dicalcium phosphate is produced.

$$Ca_3(PO_4)_2 + CaH_4(PO_4)_2 = 2Ca_2H_2(PO_4)_2.$$

Another form of phosphate of lime, met with in basic phosphate slag, is tetracalcium phosphate, $(CaO)_4P_2O_5$.

214. Reverted Phosphoric Acid.—When mono- and tricalcium phosphate react, the product is known as reverted phosphoric acid, which is insoluble in water, but is not in such form as to be unavailable as plant food. It is generally considered that the reverted phosphoric acid is available as plant food: it is soluble in a dilute solution of ammonium citrate, and is sometimes spoken of as citrate-soluble phosphoric acid. Citrate-soluble phosphoric acid may also be formed by the action upon the monocalcium phosphate of iron and aluminum compounds present as impurities in the phosphate rock. This process is a fixation change, as described in Chapter V. In an old fertilizer there may be present citrate-soluble phosphoric acid in two forms, as dicalcium phosphate and as hydrated phosphates of iron and aluminum. The citrate-soluble phosphoric acid in fertilizers is not all equally valuable as plant food because of the different phosphate compounds that may be dissolved.

215. **Available Phosphoric Acid.** — As applied to fertilizers, the term available phosphoric acid includes the water-soluble and citrate-soluble phosphoric acid. These solvents do not, under all conditions, make a sharp distinction as to the available and unavailable phosphoric acid when it comes to plant growth. Some forms of bones, which are insoluble in an ammonium citrate solution are available as plant food, and then again some forms of aluminum phosphate which are soluble are of but little value as plant food. The terms available and unavailable phosphoric acid, as applied to commercial fertilizers, refer to the solubility of the phosphates, and as a general rule their value as plant food is in accord with their solubilities. The more insoluble the less valuable the material.

216. **Phosphate Rock.** — Phosphate rock is found in many parts of the United States, particularly in South Carolina, North Carolina, Florida, Virginia, and Tennessee. The deposits occur in stratified veins, as well as in beds and pockets. There are dif-

ferent types of phosphates as hard rock, soft rock, land pebble, and river pebble. The pebble phosphates are found either on land or collected in cavities in the water courses, and are generally spherical masses of variable size. The soft rock phosphate is easily crushed, while the hard rock requires pulverizing with rock crushers. Phosphate rock usually contains from 40 to 70 per cent. of calcium phosphate, the equivalent of from 17 to 30 per cent. phosphoric acid. The remaining 30 to 60 per cent. is composed of fine sand, limestone, alumina and iron compounds, with other impurities, which often render a phosphate unsuitable for manufacturing high-grade fertilizer. Raw phosphate rock is usually sold at the mines for $1.75 to $4.50 per ton.

217. Superphosphate.—Pulverized rock phosphate known as phosphate flour, is treated with commercial sulphuric acid and soluble monocalcium phosphate obtained. The amount of sulphuric acid used is determined from the composition of the rock. Impurities as calcium carbonate and calcium fluoride react with sulphuric acid and cause a loss of acid. Ordinarily, a ton of high-grade phosphate rock requires a ton of sulphuric acid. The mixing is usually done in lead-lined tanks. A weighed amount of phosphate flour is placed in the tank, and the sulphuric acid added, through lead pipes, from the acid tower. The mixing of the acid and phosphate is done with a mechanical mixer, driven by machinery. From the mixer the material is passed into large tanks, where two or three days are allowed for the completion of the reaction. When the mass solidifies, it is ground and sold as superphosphate. In the manufacture of superphosphate, gypsum ($CaSO_4.2H_2O$) is always produced. A ton of superphosphate prepared from high-grade rock in the way outlined will contain about 40 per cent. of lime phosphates, equivalent to 18 per cent. phosphoric acid. If a poorer quality of rock is used a proportionally smaller amount of phosphoric acid is obtained. A more concentrated superphosphate is obtained by producing phosphoric acid from the phosphate rock, and then allowing the phosphoric acid to act upon fresh portions of the rock, the reactions being as follows :[63]

$$Ca_3(PO_4)_2 + 3H_2SO_4 = 3CaSO_4 + 2H_3(PO_4),$$
$$Ca_3(PO_4)_2 + 4H_3PO_4 + 3H_2O = 3[CaH_4(PO_4)_2.H_2O].$$
$$Ca_3(PO_4)_2 + 2H_3PO_4 + 12H_2O = 3[Ca_2H_2(PO_4)_2.4H_2O].$$

The phosphoric acid is separated from the gypsum before acting upon the phosphate flour. In this way, superphosphate containing from 35 to 45 per cent. of phosphoric acid is produced. When fertilizers are to be transported long distances this concentrated product is preferable. The terms 'acid' and 'superphosphate' are generally used to designate both the first product formed by the action of sulphuric acid and that produced by the phosphoric acid but of late there is a tendency to restrict the term 'acid phosphate' to the product formed by the action of sulphuric acid, and the term 'super-phosphate' to the concentrated product formed by the action of phosphoric acid.

218. Commercial Value of Phosphoric Acid.— The commercial value of phosphoric acid in fertilizers is determined by the value of the crude phosphate rock, cost of grinding and treating with sulphuric acid, and cost of transportation. The price of phosphoric acid in superphosphates usually ranges from 5 to 6 cents per pound. The field value, that is the increased yields obtained from the use of superphosphates, may not be in accord with the commercial value because so many conditions govern its use. The phosphoric acid obtained from feed-stuffs is usually considered worth about a cent a pound less than that from superphosphates. Water-soluble phosphoric acid is generally rated a half cent per pound higher than citrate-soluble phosphoric acid.

219. Phosphate Slag.—In the refining of iron ores by the Bessemer process, the phosphorus in the iron is removed as a basic slag. The lime, which is used as a flux, melts and combines with the phosphorus of the ore, forming phosphate of lime. The slag has a variable composition. The process by which the phosphorus of pig iron is removed and converted into basic phosphate slag is known as the Thomas process, and the product is sometimes called Thomas' slag. At the present time but little basic slag is produced for fertilizer purposes in this country. In Germany and some other European countries the amount used is nearly equal to the amount of superphosphate. Phosphate slag is ground to a fine powder and is applied directly to the land, without undergoing the sulphuric acid treatment. Phosphoric acid is present mainly in the form of tetracalcium phosphate, $(CaO)_4P_2O_5$.

220. Guano is the Spanish for dung, and is a concentrated form of nitrogenous and phosphate manure of interest mainly on account of its historic significance. It is a mixture of sea-fowl droppings which have accumulated along the seacoast in sheltered regions. The mixture of dung, dead animals, and debris, has undergone fermentation, and is concentrated in both nitrogen and phosphoric acid. The introduction of guano into Europe marked an important period in agriculture, inasmuch as its use demonstrated the action and importance of concentrated fertilizers. All of the best beds of guano have been exhausted and only a little of the poorer grades are now found on the market. The best qualities of guano contained from 12 to 15 per cent. of phosphoric acid, 10 to 12 per cent. of nitrogen, and from 5 to 7 per cent. of alkaline salts.

BONE FERTILIZERS

221. Raw Bones contain, in addition to phosphate of lime, $Ca_3(PO_4)_2$, organic matter which makes them slow in decomposing and slow in their action as a fertilizer. Before being used as fertilizer they should be fermented in a compost heap with wood ashes in the following way: A protected place is selected so that no losses from drainage will occur. A layer of well-compacted manure is covered with wood ashes, the bones are then added and well covered with manure and wood ashes. From three to six months should be allowed for the bones to ferment. The large, coarse pieces may then be crushed and are ready for use. The presence of fatty material in a fertilizer retards its action because fat is so slow in decomposing. Bones from which the organic matter has been removed are more active as a fertilizer than raw bones. Bones contain from 18 to 25 per cent. of phosphoric acid and from 2 to 4 per cent. of nitrogen. The amount and value of the citrate-soluble phosphoric acid in bones are extremely variable.

222. **Bone Ash** is the product obtained when bones are burned. It is not extensively used as a fertilizer because of the greater commercial value of bone-black. It contains about 36 per cent. of phosphoric acid, and is more concentrated than raw bones.

223. **Steamed Bones.** — Raw bones are subjected to superheated steam to remove the fat and ossean which are used for making soap and glue; they are then pulverized and sold as fertilizer under the name of bone meal, which contains from 1.5 to 2.5 per cent. of nitro-

gen and from 22 to 29 per cent. of phosphoric acid. Steamed bones make a more active fertilizer than raw bones. Occasionally, well-prepared bone meal is used for feeding pigs and fattening stock in the same way that flesh meal is used.

224. Dissolved Bone. — When bones are treated with sulphuric acid as in the manufacture of superphosphates the product is called dissolved bone. The tricalcium phosphate undergoes a change to more available forms, as described, and the nitrogen is rendered more available. Dissolved bone contains from 2 to 3 per cent. of nitrogen and from 15 to 17 per cent. of phosphoric acid.

225. Bone-black. —When bones are distilled bone-black is obtained. It is extensively employed for refining sugar, and after it has been used and lost its power of decolorizing solutions, it is sold as fertilizer. It contains about 30 per cent. phosphoric acid and is a concentrated phosphate fertilizer.

226. Use of Phosphate Fertilizers. — The amount of phosphoric acid advisable to apply to crops, varies with the nature of the soil and the kind of crop to be produced. On a poor soil 400 pounds of superphosphate per acre is an average application. It is usually applied as a top dressing just before seeding, and may be placed near the hills of corn or potatoes, but not in contact with the seed. It is not advisable to make heavy applications of superphosphates at long intervals, because the process of fixation may take place to such an extent that crops are unable to utilize the fertilizer. Lighter and more frequent applications are preferable. Phosphates should not be mixed with lime carbonate or with loam before spreading.[21] It is best to apply the fertilizer directly to the land. Phosphates may be used in connection with farm manures. Many soils which contain liberal amounts of total phosphoric acid are improved with a light dressing of superphosphates. Such soils, however, should be more thoroughly cultivated, and manured with farm manures, to make the phosphates available. There is frequently an apparent lack of phosphoric acid in the soil when in reality the trouble is due to other causes, as lack of organic matter to combine with the phosphates or to a deficiency of lime. Before using phosphate fertilizers, careful field tests should be made to determine if the soil is in actual need of available phosphoric acid. Directions for making these tests are given in Chapter X.

227. How to Keep the Phosphoric Acid Available. — Phosphoric acid associated with organic matter in a moderately alkaline soil, is more available than that in acid soils. Soft phosphate rock may be mixed with manure or materials like cottonseed meal and made slowly available for crops. Soils which have a good stock of phosphoric acid, when kept well manured, and occasionally limed if necessary, contain a liberal supply of available phosphoric acid. As an illustration, the following example of two soils from adjoining farms, which have been cropped and manured differently, may be cited:[30]

	Soil well manured and crops rotated. Per cent.	No manure and continuous wheat raising. Per cent.
Total phosphoric acid....	0.20	0.20
Humus....................	4.25	1.62
Humic phosphoric acid ..	0.06	0.02

It is more economical to keep the insoluble phosphoric acid of the soil in available forms by the use of farm manures than it is to purchase superphosphates.

CHAPTER VIII

POTASH FERTILIZERS

228. Potassium an Essential Element of Plant Food. — Potassium is one of the three elements most essential as plant food. When it is removed from a soil plants are unable to develop. Oats seeded in a soil from which the potash only had been extracted made the total growth shown in the illustration (Fig. 32). When potash is present in the soil in liberal amounts vigorous plants are produced. Potash, like phosphoric acid and nitrogen, is utilized by crops in the early stages of growth. Potassium does not accumulate in seeds to the same extent as phosphoric acid and nitrogen, but is present mainly in stems and leaves, consequently when straw crops are utilized in producing manure the potash is not lost or sold from the farm. But with ordinary grain farming excessive losses of potash do occur, particularly when the straw is burned and the ashes are wasted.

Fig. 32. Oat plant grown without potash.

229. Amount of Potash Removed in Crops. — In grain crops from 35 to 60 pounds of potash per acre are removed from the soil. For grass crops more potash is required than for grains, while roots and tubers require more than grass. The approximate amount of potash removed in various crops is given in the following table:[37]

	Potash per acre. Lbs.
Wheat, 20 bu	7
Straw, 2,000 lbs	28
Total	35
Barley, 40 bu	8
Straw, 3,000 lbs	30
Total	38
Oats, 50 bu	10
Straw, 3,000 lbs	35
Total	45
Corn, 65 bu	15
Stalks, 3,000 lbs	45
Total	60
Peas, 30 bu	22
Straw, 3,500 lbs	38
Total	60
Flax, 15 bu	19
Straw, 1,800 lbs	8
Total	27

Mangels, 10 tons	150
Meadow hay, 1 ton	45
Clover hay, 2 tons	66
Potatoes, 150 bushels	75

230. Amount of Potash in Soils. — In ordinary soils there are from 3,500 to 12,000 pounds of potash per acre to the depth of one foot. Many soils with apparently a good stock of total potash give excellent results when a light dressing of potash salts is applied. The amount of available potash in the soil is more difficult to estimate than the available phosphoric acid. There is also a great difference in crops as to their power of obtaining potash. Some require greater help in procuring this element than others. A lack of available potash is sometimes indirectly due to a deficiency of other alkaline matter in the soil, which prevents the necessary changes taking place in order that the potash may be liberated as plant food.

231. Sources of Potash in Soils. — The main source of the soil potash is feldspar, which, after disintegration, is broken up into kaolin and potash compounds. Mica and granite also, in some localities, contribute liberal amounts. The most valuable forms of potash are the zeolitic silicates. The amount of water-soluble potash, except in alkaline soils, is extremely small. By the action of many fertilizers the potash compounds undergo changes in composition. For example, the gypsum which is always present in acid phosphates, liberates some potash. The potash compounds of the soil are in various degrees of complexity from forms soluble in dilute acids to insoluble minerals as feldspar.

232. **Commercial Forms of Potash.** — Prior to the introduction of the Stassfurt salts, wood ashes were the main source of potash. Since the discovery and development of the Stassfurt mines, the natural products as kainit, and muriate and sulphate of potash have been extensively used for fertilizing purposes. A small amount of potash is also obtained from waste products as tobacco stems, cottonseed hulls, and the refuse from beet-sugar factories.

STASSFURT SALTS

233. **Occurrence.**[63] — The Stassfurt mines were first worked with the view of procuring rock salt. The presence of the various compounds of potash, soda, and magnesia, associated with the layers of rock salt, were regarded as troublesome impurities, and attempts were made by sinking new shafts to avoid them, but with the result of finding them in greater abundance. About 1864 their value as potash fertilizers was established. The mines are now owned and worked by a syndicate. It is supposed that at one time the region about the mines was submerged and filled with sea-water. The tropical climate of that geological period caused rapid evaporation, which resulted in forming mineral deposits, the less soluble material as lime sul-

phate being first deposited, then a layer of rock salt, and finally layers of potash and magnesium salts in the order of their solubility.

234. **Kainit** is a mineral composed of potassium sulphate, magnesium sulphate, magnesium chloride, and water of crystallization. As it comes from the mine it is mixed with gypsum, salt, potassium chloride, and other bodies. Kainit contains from 12 to 12.50 per cent. of potash, and is one of the most important of the Stassfurt salts. It is extensively used as a potash fertilizer, and is also mixed with other materials and sold as a commercial fertilizer. The magnesium chloride causes it to absorb water, and the presence of other compounds results in the formation of hard lumps, whenever kainit is kept for a long time. Kainit is soluble in water, and can be used as a top dressing at the rate of 75 to 200 pounds or more per acre.

235. **Sulphate of Potash.** — High-grade sulphate of potash is prepared from some of the crude Stassfurt salts, and may contain as high as 97 per cent. K_2SO_4. Low-grade sulphate of potash is about 90 per cent. pure. High-grade sulphate of potash contains about 50 per cent. of potassium oxide (K_2O), and is one of the most concentrated forms of potash fertilizer. It is particularly valuable because it can be safely used on crops as tobacco and potatoes which would be injured in quality if muriate of potash were applied, or if much chlorine were present.

236. Miscellaneous Potash Salts. — Carnallit, 9 per cent. K_2O, — composed of $KCl.MgCl_2.6H_2O$. Polyhalit, 15 per cent. K_2O,—composed of $K_2SO_4.Mg SO_4.(CaSO_4)_2.H_2O$. Krugit, 10 per cent. K_2O,—composed of $K_2SO_4.MgSO_4.(CaSO_4)_4.H_2O$. Sylvinit, 16 to 20 per cent. K_2O,—composed of KCl.NaCl and impurities. Kieserit, 7 per cent. K_2O, —composed of $MgSO_4$ and carnallit.

237. Wood Ashes. — For ordinary agricultural purposes, wood ashes are the most important source of potash. Ashes are exceedingly variable in composition. When leached the soluble salts are extracted and there is left only about 1 per cent. of potash. In unleached ashes the amount of potash ranges from 2 to 10 per cent. Soft wood ashes contain much less potash than hard wood ashes. Goessmann gives the following as the average of 97 samples of ashes :[64]

	Average composition. Per cent.	Range. Per cent.
Potash	5.5	2.5 to 10.2
Phosphoric acid	1.9	0.3 to 4.0
Lime	34.3	18.0 to 50.9

In 10,000 pounds of wood.	Potash. Lbs.	Phosphoric acid. Lbs.
White oak	10.6	2.5
Red oak	14.0	6.0
Ash	15.0	1.1
Pine	0.8	0.7
Georgia pine	5.0	1.2
Dogwood	9.0	5.7

238. Action of Ashes on Soils. — In ashes, the potash is present mainly as potassium carbonate. Ashes are usually regarded as a potash fertilizer only, but they also contain lime and phosphoric acid, and may be very beneficial in supplying these elements. They are valuable too because they add alkaline matter to the soil, which corrects acidity and aids nitrification. A dressing of ashes improves the mechanical condition of many soils by binding together the soil particles. This property is well illustrated in the so-called "Gumbo" soils, which contain so much alkaline matter that the soil has a soapy taste and feel, and when plowed the particles fail to separate.

239. Leached Ashes. — When ashes are leached the soluble salts are extracted, and the insoluble matter which is left is composed mainly of calcium carbonate and silica.[65]

	Unleached ashes. Per cent.	Leached ashes. Per cent.
Water	12.0	30.0
Silica, etc	13.0	13.0
Potassium carbonate	5.5	1.1
Calcium "	61.0	51.0
Phosphoric acid	1.9	1.4

240. Alkalinity of Leached and Unleached Ashes. — A good way to detect leached ashes is to determine the alkalinity in the following way: Weigh out 2 grams of ashes into a beaker, add 100 cc. distilled water, and heat on a sand-bath nearly to boiling, cool, and filter. To 50 cc. of the filtrate add about 3 drops of cochineal indicator, and then a standard solution of hydrochloric acid from a burette until the solution is neutral. If a standard solution of acid cannot be procured, one containing 15 cc. concentrated hydrochloric acid per liter of distilled water may be used for comparative purposes. Leached ashes require less than 2 cc. of acid to neutralize the alkaline matter in 1 gram while unleached ashes require from 10 to 18 cc. In purchasing wood ashes, if a chemical analysis cannot be secured, the alkalinity of the ash should be determined.

241. Coal and Other Ashes. — Since the amount of phosphoric acid and potash in coal ashes is very small, they have but little fertilizer value. Soft-coal ashes contain more potash than those from hard coal, but it is held in such forms of combination as to be of but little value.

The ashes from sawmills where soft wood is burned and the ashes are unprotected, are nearly worthless. When peat-bogs are burned over, large amounts of ashes are produced. If the bogs are covered with timber, the ashes are sometimes of sufficient value to warrant their transportation and use.

	Potash. Per cent.	Phosphoric acid. Per cent.
Hard coal	0.10	0.10
Soft coal	0.40	0.40
Sawmill ashes[13]	1.20	1.00
Peat-bog ashes[13]	1.15	0.54
Peat-bog ashes (timbered)[13]	3.68	2.56
Tobacco stems	4.00	7.00
Cottonseed hulls	20.00	7.00

242. Commercial Value of Potash. — The market value of potash is determined from the selling price of high-grade sulphate of potash and kainit. Ordinarily, the price per pound of potash varies from 4 to 5 cents. As in the case of both nitrogen and phosphoric acid, the market and the field values may be entirely at variance. Before potash salts are used, careful field tests should be made to determine the actual condition of the soil as to its needs in potash.

243. Use of Potash Fertilizers. — Wood ashes, or Stassfurt salts, should not be used in excessive amounts. Not more than 300 pounds per acre should be applied unless the soil is known to be markedly deficient, and previous tests indicate that larger amounts are safe and advisable. Potash fertilizers should be evenly spread and not allowed to come in contact with plant tissue. They should be used early in the spring before seeding or before the crop has made much growth. Wood ashes make an excellent top dressing for grass lands, particularly where it is desired to encourage the growth of clover. There are but few crops or soils that are not greatly benefited by a light application of wood ashes, and none should ever be allowed to leach or waste about a farm.

When a potash fertilizer is used, a dressing of lime will frequently be beneficial. The potash undergoes fixation, and when it is liberated there should be some basic material as lime to take its place. Goessmann observed that land manured for several years with potassium chloride finally produced sickly crops, but that an application of slaked lime restored a healthy appearance to succeeding crops.[66] If the soil is well stocked with lime its joint use with potash fertilizers is not necessary.

CHAPTER IX

LIME AND MISCELLANEOUS FERTILIZERS

244. Calcium an Essential Element of Plant Food. — Calcium is present in the ash of all plants, and is usually more abundant in soils than phosphorus or potassium. It takes an essential part in plant growth, and whenever withheld growth is checked. The effect of removing calcium from the soil is shown in the illustration (Fig. 33), which gives the total growth made by an oat plant under such a condition.

Fig. 33.
Oat plant grown without lime.

Plants grown on soils deficient in calcium compounds, lack hardiness. They are not so able to withstand drought, or climatic changes, as plants grown on soils well supplied with this element. Calcium does not accumulate in the seeds of plants, but is present mainly in the leaves and stems where it takes an important part in the production of new tissue. The term lime is used in speaking of the calcium oxide content of soils and crops.

245. Amount of Lime Removed in Crops.[37] —

	Pounds per acre.
Wheat, 20 bushels	1
Straw, 2000 pounds	7
Total	8
Corn, 65 bushels	1
Stalks, 3000 pounds	11
Total	12
Peas, 30 bushels	4
Straw, 3500 pounds	71
Total	75
Flax, 15 bushels	3
Straw, 1800 pounds	13
Total	16
Clover, 4000 pounds	75

Clover and peas remove so much lime from the soil that they are often called lime plants. The amount required by grain and hay is small compared with that required for a clover or pea crop.

246. Amount of Lime in Soils. — There is no element in the soil in such variable amounts as calcium. It may be present from a few hundredths of a per cent. to twenty per cent.; soils which contain from 0.4 to 0.5 per cent. are usually well supplied. The lime in a soil takes an important part in soil fertility; when deficient, humic acid may be formed, nitrification checked, and the soil particles will lack binding material.

247. Different Kinds of Lime Fertilizers. — By the term 'lime fertilizer' is usually meant land plaster ($CaSO_4.2H_2O$). Occasionally quicklime (CaO) and slaked lime ($Ca(OH)_2$) are used on exceedingly sour land. In general a lime fertilizer is one which supplies the element calcium; common usage, however, has restricted the term to sulphate of lime.

248. Action of Lime Fertilizers upon Soils. — Lime fertilizers act both chemically and physically. Chemically, lime unites with the organic matter to form humate of lime and prevent the formation of humic acid. It aids in nitrification and acts upon the soil, liberating potassium and other elements of plant food. Physically, lime improves capillarity, precipitates clay when suspended in water, and prevents losses, as the washing away of fine earth.

249. Action of Lime upon Organic Matter. — When soils are deficient in lime, an acid condition may develop to such an extent as to be injurious to vegetation. In fact nitrogen, phosphoric acid, and potash may all be present in liberal amounts, but in the absence of lime poor results will be obtained. Experiments at the Rhode Island Experiment Station indicate that there are large areas of acid soils in the Eastern States which are much improved when treated with air-slaked lime.[67] There is a great difference in the power of plants to live in acid soils. Agricultural plants are particularly sensitive, while many weeds have such strong power of endurance that they are able to thrive in the presence of acids. The character of the weeds frequently reflects the character of the soil as to acidity, in the same way that an "alkali" soil is indicated by the plants produced.

250. Lime Liberates Potash. — The action of lime upon soils well stocked with potash results in the fixation of the lime and the liberation of the potash; the reaction takes place in accord with the well-known exchange of bases. The extent to which potash may be liberated by lime depends upon the firmness with which the potash is held in the soil. Boussingault found that when clover was limed there was present in the crop three times as much potash as in a similar crop not limed. His results are as follows:[68]

	Kilos per hectare.			
	In crop not limed.		In limed crop.	
	First year.	Second year.	First year.	Second year.
Lime	32.2	32.2	79.4	102.8
Potash	26.7	28.6	95.6	97.2
Phosphoric acid	11.0	7.0	24.2	22.9

The indirect action of land plaster upon Western prairie soils in liberating plant food, particularly potash and phosphoric acid, is unusually marked. Laboratory experiments show that small amounts of gypsum are quite active in rendering potash, phosphoric acid, and even nitrogen soluble in the soil water.[5]

251. Quicklime and Slaked Lime. — When it is desired to correct acidity slaked lime is used. Air-slaked lime is not as valuable as water-slaked lime. Quicklime cannot be used on land after a crop has been seeded. Both slaked lime and quicklime should be applied some little time before seeding and not to the crops. The action of quicklime upon organic matter is so rapid that it destroys vegetation. Slaked lime is less injurious to vegetation.

252. Pulverized Lime Rock. — In some localities pulverized lime rock is used. It may be applied as a top-dressing in almost unlimited amounts. It is most beneficial on light, sandy soils, where it performs the function of fine clay as well as being beneficial in its chemical action. Not all soils are alike responsive to applications of limestone, and before using, it is best to determine to what extent it will be beneficial. There are no conditions where limestone is injurious to soil or crop.

253. Marl. — Underlying beds of peat, deposits of marl are occasionally found. Marl is a mixture of disintegrated limestone and clay, and contains variable amounts of calcium carbonate, phosphoric acid, and potash. When peat and marl are found together they may be used jointly with manure as described in Section 175. Many sandy lands in the vicinity of peat and marl deposits would be greatly improved, both physically and chemically, by the use of these materials.

254. Physical Action of Lime. — The addition of lime fertilizers to sandy soils improves their general physical condition. Heavy clays lose their plasticity when limed; the fine clay particles are cemented and act as sand, which improves the mechanical condition of the soil. The physical action of lime upon soils is well illustrated in the case of 'loess soils,' which are composed of clay and limestone. The lime cements the clay particles and forms compound grains, making the soil more permeable, and more easily tilled. The improved physical condition alone which follows the application of lime fertilizers, is frequently sufficient to warrant their use.

255. Application of Lime Fertilizers. — Lime is generally used as a top-dressing on grass lands at the rate of 200 to 500 pounds per acre. Excessive applications are undesirable. Lime as gypsum is particularly valuable when applied to land where crops are grown which assimilate large amounts of lime. It should be remembered that it is not a complete, but mainly an indirect, fertilizer.

If used to excess it may get the soil in such a condition that no more plant food can be rendered available. A common saying is "Lime makes the father rich but the son poor."[21] This is true, however, only when lime is used in excess. When used occasionally in connection with other manures, it has no injurious effects upon the soil and is a valuable fertilizer, especially where clover is grown with difficulty.

MISCELLANEOUS FERTILIZERS

256. Salt is frequently used as an indirect fertilizer. Sodium and chlorine, the two elements of which it is composed, are not absolutely necessary for normal plant growth. When salt is applied to the soil and the sodium undergoes fixation, potassium may be liberated. An early experiment of Wolff illustrates this point: a buckwheat plot fertilized with salt produced a crop with more potash and less sodium than a similar unfertilized plot.

Salt may be used to check the rank growth of straw during a rainy season, and thus prevent loss of the crop by lodging. It should not be used in excessive amounts, as it is destructive to vegetation; 200 pounds per acre is a fair application. Salt also improves the physical condition of the soil by increasing the surface-tension of the soil water. Salt should not be used on a tobacco or potato crop, because it injures the quality of the product.

257. Magnesium Salts. — Magnesium is present in the ash of all plants, and is an essential element of plant growth. Usually soils are so well stocked with this element that it is not necessary to apply it in fertilizers. Some of the magnesium salts, as the chloride, are injurious to vegetation, but when associated with lime as carbonate, magnesia imparts fertility. In many of the Stassfurt salts magnesium is present.

258. Soot. — The deposits formed in boilers and chimneys when wood and soft coal are burned contain small amounts of potash and phosphoric acid. They are valuable mainly as mechanical fertilizers imparting the properties of organic matter. There is but little plant food in soot, as shown by the following analysis:

	Soft-coal soot. Per cent.[13]	Hard-wood soot. Per cent.[69]
Potash	0.84	1.78
Phosphoric acid	0.75	0.96

259. Seaweeds. — Seaweeds are rich in potash and near the sea coast are extensively used for fertilizers.

	Composition of mixed seaweed. Per cent[69]
Water	81.50
Nitrogen	0.73
Potash	1.50
Phosphoric acid	0.18

260. Strand Plant Ash. — Weeds and plants produced on waste land along the sea are in many European countries burned, and the ashes used as fertilizer on other lands. By this means waste land is made to produce fertilizer for fields which are tillable. The amount of fertility removed in weeds is usually greater than that in agricultural plants, because weeds have a greater power of obtaining food from the soil. When wheat or other grain is raised, and a small crop of grain and a large crop of weeds are the result, there is more fertility removed from the soil than if a heavy stand of grain were obtained. The ashes of strand plants and weeds are extremely variable in composition.

261. Wool Washings and Waste. — The washings from wool contain sufficient potash to make this material valuable as a fertilizer. In wool there is a high per cent. of potash, which is soluble, and readily removed in the washings. Wool waste may contain from 1 to 5 per cent. of potash and from 4 to 7 per cent. of nitrogen in somewhat inert forms.

CHAPTER X

COMMERCIAL FERTILIZERS AND THEIR USE

262. Development of the Commercial Fertilizer Industry. — The commercial fertilizer industry owes its origin to Liebig's work on plant ash. The first superphosphate was made by Sir J. B. Lawes, about 1840, from spent bone-black and sulphuric acid. His interest had previously been attracted to the use of bones by a gentleman who farmed near him, "who pointed out that on one farm bone was invaluable for the turnip crop, and on another farm it was useless."[43] Since 1860 the commercial fertilizer industry in this country has developed rapidly, until now the amount of money expended in purchasing commercial fertilizers and amendments is estimated at $60,000,000 annually. Nearly all of this sum is expended in less than a quarter of the area of the United States.

263. Complete Fertilizers and Amendments. — The term commercial fertilizer is applied to those materials which are made by the mixing of different substances which contain plant food in concentrated forms. When a commercial fertilizer contains nitrogen, phosphoric acid, and potash, it is called a complete fertilizer, because it supplies the three elements which are liable to be most deficient. Materials as sodium nitrate which supply only one element are called amendments. It frequently happens that a soil requires only one element in order to produce good crops. In such cases only the one element needed should be supplied. Complete fertilizers are sometimes used when the soil is only in need of an amendment.

264. Variable Composition of Commercial Fertilizers. — Since commercial fertilizers are made by mixing various materials which contain different amounts of nitrogen, phosphoric acid, and potash, it follows that they are extremely variable in composition and value. No two samples are the same, hence the importance of knowing the composition of every separate brand purchased. The composition of fertilizers is varied to meet the requirements of different soils and crops. Some fertilizers are made rich in phosphoric acid, while others are rich in nitrogen and potash.

265. How a Fertilizer is Made. — The most common materials used in making complete fertilizers are: Nitrate of soda, kainit, and dissolved phosphate rock. These materials have about the following composition:

Nitrate of soda........	15.5 per cent. nitrogen.
Kainit................	12.5 per cent. potash.
Dissolved phosphate...	14.0 per cent. phosphoric acid.

The fertilizer may be made rich or poor in any one element. Many fertilizers contain about twice as much potash as nitrogen and five times as much phosphoric acid as potash. In order to make a ton of such a fertilizer it would be necessary to take about

	Pounds.
Nitrate of soda	225
Kainit	425
Phosphate	1350

The ton of fertilizer would then contain about 35 pounds of nitrogen, 189 pounds of phosphoric acid and 53 pounds of potash. These amounts are determined by multiplying the percentage composition by the weight of material taken :

		Pounds.
Nitrogen	225 × 0.155 =	34.9
Potash	425 × 0.125 =	53.1
Phosphoric acid	1350 × 0.14 =	189.0

The fertilizer would then contain about 1.75 per cent. nitrogen, 2.65 per cent. potash, and 9.45 per cent. phosphoric acid. The percentage amounts are obtained by dividing the total pounds by 20. This fertilizer, if made at home from materials purchased in the market, would cost, exclusive of transportation and mixing, $18.79.

	Pounds.	Cost.	
Nitrogen	34.9 @	14½ cents =	$5.06
Phosphoric acid	189.0 @	6 cents =	11.34
Potash	53.1 @	4½ cents =	2.39
		Total	$18.79

A more concentrated fertilizer could be prepared by using high-grade sulphate of potash, superphosphate, and ammonium sulphate. A fertilizer composed of these ingredients would contain:

Pounds.	Containing per cent.	Total pounds.		Value.	Percentage composition of fertilizer.
300 Sulphate of ammonia	20 N	60 @	14½ cents =	$8.70	3.00
500 Sulphate of potash	50 K_2O	250 @	4½ cents =	11.25	12.50
1200 Superphosphate	35 P_2O_5	420 @	6 cents =	25.20	21.0
			Total	$45.15	

So concentrated a fertilizer as the preceding is rarely, if ever, found on the market, although the price, $45.15 per ton, is frequently charged. This example is given to show the composition and trade value of one of the most concentrated fertilizers that could be produced.

Any one of the different materials mentioned in the chapters on special fertilizers could be used, as dried blood, tankage, nitrate of soda, sulphate of ammonia, raw bone, dissolved bone, raw phosphate rock, dissolved phosphate rock, basic slag, kainit, muriate or sulphate of potash, and many others. Inasmuch as each of these materials has a different value, it follows that fertilizers, even of the same general composition, may have widely different crop-producing powers.

266. Inert Forms of Plant Food in Fertilizers. — A fertilizer of the same general composition as the first example could be made from feldspar rock, apatite rock, and leather. The leather contains nitrogen, the apatite contains phosphoric acid, and the feldspar, potash. Such a fertilizer would have no value when used on a crop, because all of the plant food elements are present in unavailable forms. Hence, in purchasing fertilizers, it is necessary to know not only the percentage composition, but also the nature of the materials from which the fertilizer was made.

267. Inspection of Fertilizers. — In many states laws have been enacted regulating the manufacture and sale of commercial fertilizers, and provision is made for inspection and analysis of all brands offered for sale. The label on the fertilizer package must specify the percentage amounts of nitrogen, available phosphoric acid and potash. Inspection has been found necessary in order to protect the farmer and the honest manufacturer.

Occasionally a fraud is revealed like the following:[70]

Natural plant food $25 to $28 per ton.

Composition.	Per cent.
Total phosphoric acid	22.21
Insoluble " "	20.81
Available " "	1.40
Potash soluble in water	0.13

Actual value per ton, $1.52.

268. Mechanical Condition of Fertilizers.—When a fertilizer is purchased, the mechanical condition should also be considered. The finer the fertilizer, as a rule, the better it is for promoting crop growth. Some combinations of plant food produce fertilizers which become so hard and lumpy that it is difficult to crush the lumps before spreading. The mass must be pulverized so as to be evenly distributed, otherwise the plant food will not be economically used. A fertilizer that passes through a sieve with holes 0.25 mm. in diameter is more valuable and can be used to better advantage than one of the same composition that requires a 0.5 mm. sieve.

269. Forms of Nitrogen in Commercial Fertilizers. —Nitrogen is present in commercial fertilizers in three forms: (1) Ammonium salts, (2) nitrates, and (3) organic nitrogen. The organic nitrogen is divided into two classes: (*a*) soluble in pepsin solution, and (*b*) insoluble in pepsin solution. The relative values of these different forms of nitrogen are discussed in Chapter IV. Three fertilizers may have the same amount of total nitrogen and still have entirely different crop-producing powers.

Nitrogen as:	No. 1. Per cent.	No. 2. Per cent.	No. 3. Per cent.
Ammonium compounds	1.75	0.25	0.10
Nitrates	0.15	0.15	0.10
Organic nitrogen:			
Soluble in pepsin	0.10	1.25	0.55
Insoluble in pepsin	...	0.35	1.25
Total	2.00	2.00	2.00

In purchasing fertilizers it is important to know not only the amount of nitrogen, but also the form in which it is present. In No. 3 the nitrogen is in inert forms like leather, while in No. 2 it is largely in the form of dried blood, and No. 1 has mainly ammonium compounds. Each of these fertilizers, as explained in the chapter on nitrogenous manures, has a different plant food value.

270. Phosphoric Acid. — There are three forms of phosphoric acid in commercial fertilizers: (1) Water-soluble, (2) citrate-soluble, and (3) insoluble. The water- and citrate-soluble are called the available phosphoric acid. In most fertilizers the phosphoric acid is derived from dissolved phosphate rock, and is in the form of monocalcium phosphate. The citrate-soluble is mainly dicalcium phosphate with variable amounts of iron and aluminum phosphates in easily soluble forms. The insoluble phosphoric acid is tricalcium and other phosphates which are soluble only in strong mineral acids. The insoluble phosphoric acid in fertilizers is considered as having but little value. As in the case of nitrogen three fertilizers may have the same total amount of phosphoric acid and yet have entirely different values.

	No. 1. Per cent.	No. 2. Per cent.	No. 3. Per cent.
Water-soluble phosphoric acid	8.00	0.25	0.25
Citrate-soluble " "	1.50	8.00	0.75
Insoluble " "	0.50	1.75	9.00
Total	10.00	10.00	10.00

No. 3 is of but little value; the fertilizer contains insoluble phosphate rock or some material of the same nature. No. 1 is the most valuable, because it contains the least insoluble phosphoric acid. This fertilizer contains dissolved phosphate rock or dissolved bone. No. 2 is composed of such materials as the best grade of basic slag or roasted aluminum phosphate or fine steamed bone.

271. **Potash.** — The three forms of potash in fertilizers are: (1) water-soluble, (2) acid-soluble, and (3) insoluble. Materials as sulphate of potash, kainit, and muriate of potash, which are soluble in water, belong to the first class. In some states the fertilizer laws recognize only the water-soluble potash. In the second class are found materials like tobacco stems and the organic forms of potash. Substances like feldspar, which contain insoluble potash, are of no value in fertilizers. As a rule, the potash in commercial fertilizers is soluble in water; in only a few cases are acid-soluble forms met with. Insoluble potash would be considered an adulterant.

272. **Misleading Statements on Fertilizer Packages.** — Occasionally the percentage amounts of nitrogen, phosphoric acid, and potash are stated in misleading ways as ammonia, sulphate of potash, and bone phosphate of lime. Inasmuch as 14/17 of ammonia is nitrogen, the percentage figure for ammonia is proportionally greater than the nitrogen. And so with sulphate of potash which contains about 50 per

cent. potash. This method of stating the composition can be considered in no other way than a fraud, especially when the fertilizer contains no sulphate of potash, but cheaper materials, and the phosphoric acid is not derived from bone.

273. Estimated Commercial Value of Fertilizers. —The estimated value of a commercial fertilizer is obtained from the percentage composition and the trade value of the materials used. Suppose that two fertilizers are selling for $25 and $30, respectively, each having a different composition, the estimated values would be obtained in the following way :

COMPOSITION OF FERTILIZERS.

	No. 1. Selling price $25. Per cent.	No. 2. Selling price $30. Per cent.
Nitrogen as nitrates	1.50	2.10
Phosphoric acid, available	8.00	10.00
" " insoluble	2.00	0.50
Potash (water-soluble)	2.00	3.50

POUNDS PER TON.

	No. 1.	No. 2.
Nitrogen	1.50 × 20 = 30	2.10 × 20 = 42
Phosphoric acid	8.0 × 20 = 160	10.0 × 20 = 200
Potash	2.0 × 20 = 40	3.5 × 20 = 70

ESTIMATED VALUE.

	No. 1.	No. 2.
Nitrogen	30 × 0.145 = $4.35	42 × 0.145 = $6.09
Phosphoric acid	160 × 0.06 = 9.60	200 × 0.06 = 12.00
Potash	40 × 0.045 = 1.80	70 × 0.045 = 3.15
	$15.75	$21.24

Difference between estimated value and selling price, No. 1, $9.25; No. 2, $8.76.

274. Home Mixing. — At the New Jersey Experiment Station it has been shown that "the charges of the manufacturers and dealers for mixing, bagging, shipping, and other expenses are on the average $8.50 per ton, and also that the average manufactured fertilizer contains about 300 pounds of actual fertilizing constituents per ton. These figures are practically

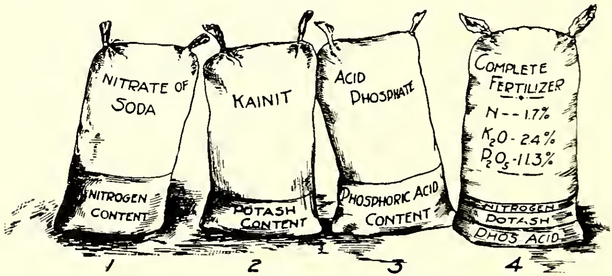


Fig. 34. Composition of Fertilizers.

true of other states where large quantities of commercial fertilizers are used."[71] In states where smaller amounts are used the difference between the estimated cost and selling price is greater than $8.50.

These facts emphasize the economy of home mixing. The difference in price between the raw materials and the product sold is frequently so great that it is an advantage for the farmer to purchase the raw materials, as sulphate of potash, nitrate of soda, and acid phosphate, and mix them as desired. By so doing a fertilizer of any composition may be prepared and there is less danger of securing an inferior article. Of course it is not possible by means of shovels and sieves to accomplish as thorough mixing of the ingredients as with machinery.

FORMULA NO. 1.

	Pouuds.		Pounds.	Percentage composition of fertilizer.
Nitrate of soda......	500	containing nitrogen.....	77.5	3.87
Acid phosphate.....	1200	containing phos. acid...	168.0	8.40
Sulphate of potash..	300	containing potash.......	150.0	7.50
Total		....	395.5	

FORMULA NO. 2.

Nitrate of soda......	250	containing nitrogen.....	38.7	1.99
Acid phosphate	900	containing phos. acid...	126.0	6.3
Sulphate of potash ..	450	containing potash.......	225.0	11.5
Plaster, etc	400			
Total		....	389.7	

FORMULA NO. 3.

Nitrate of soda......	200	containing nitrogen.....	31.0	1.55
Acid phosphate.....	1500	containing phos. acid...	210.0	10.50
Sulphate of potash ..	150	containing potash.......	75.0	5.75
Plaster, etc	150			
Total		....	316.0	

275. **Fertilizers and Tillage.**—Commercial fertilizers cannot be made to take the place of good tillage, which is equally as important when fertilizers

are used as when they are omitted. Scant crops are as frequently due to the want of proper tillage as to the absence of plant food. Poor cultivation results in getting the soil out of condition; then instead of thoroughly preparing the land, commercial fertilizers are resorted to, and the conclusion is reached that the soil is exhausted, when in reality it is suffering for the want of cultivation, for a dressing of land plaster, for farm manures, or for a change of crops. There is no question but what better tillage, better care and use of farm manures, the culture of clover and the systematic rotation of crops would result in greatly reducing the $60,000,000 annually spent for commercial fertilizers, without reducing the yield of crops. The better the cultivation, the less the amount of commercial fertilizer required.

276. Abuse of Commercial Fertilizers. — When a soil produces poor crops, a complete fertilizer is frequently used when an amendment only is needed. Restricted crop production in long cultivated soils is due to deficiency of available nitrogen. If the nitrogen were supplied, improved cultivation would generally furnish the available potash and phosphoric acid, but instead of providing the one element needed, others which may already be present in the soil in liberal amounts, are often supplied at a great expense. Another abuse of fertilizers is their application to the wrong crop. A heavy application of potash fertilizer to a wheat crop grown on a clay soil, or an application of nitrate of soda on land seeded to clover, or of land plaster to flax grown on a limestone soil, would be a useless waste of money.

277. Proper Use of Fertilizers. — In order to make the best use of commercial fertilizers, both the soil and the crop must be carefully considered. All crops do not possess the same power of obtaining food from the soil; turnips, for example, have very restricted powers of phosphate assimilation, hence they require special manuring with phosphates. Wheat requires help in obtaining its nitrogen. A wheat crop will starve for the want of nitrogen, while an adjoining corn crop will scarcely feel its need. Wheat has strong power of assimilating potash compounds, while clover has less. Hence in the proper use of fertilizers the power of the plant to obtain its food must be considered. An application of potash to clover, nitrogen to wheat, and phosphoric acid to turnips, would be a judicious use of these fertilizers, while if a mixture of the three elements were applied to each crop alike, the clover would not be particularly benefited by the nitrogen or the wheat by the potash. Before commercial fertilizers are used, careful field trials should be made with different crops.

FIELD TESTS WITH FERTILIZERS

278. Experimental Plots. — A piece of land well tilled and of uniform texture, should be used for field trials with fertilizers. After preparation for the crop, small plots, 1/20 of an acre, are staked off. A convenient size is, length 204 feet, width 10 feet 8 inches, area 2176 square feet. Between each plot a strip 3 feet wide should be left. In these experiments the plan is to apply one element or a combination of elements to a plot and compare the results with other plots treated differently.[69]

279. Preliminary Trials. — It is best to make preliminary trials one year and verify the conclusions the next. In making the tests the first year eight plots are necessary and fertilizers are applied in the following way:

The first plot receives no fertilizer and is used as the basis for comparison.

The second plot receives a dressing of 8 pounds of nitrate of soda, 16 pounds acid phosphate, and 8 pounds sulphate or muriate of potash.

The third plot receives nitrogen and phosphoric acid.

The fourth plot receives nitrogen and potash.

The fifth plot receives nitrogen.

The sixth plot receives phosphoric acid and potash.

The seventh plot receives potash.

The eighth plot receives phosphoric acid.

No fertilizer. 1.	N P_2O_5 K_2O 2.	N P_2O_5 3.	N K_2O 4.
N 5.	P_2O_5 K_2O 6.	K_2O 7.	P_2O_5 8.

Should good results be obtained on plot No. 3, the indications are that there is a deficiency of the two elements nitrogen and phosphoric acid. An increased yield from No. 4 indicates deficiency of nitrogen and potash. Under such conditions the use of a complete fertilizer would be unnecessary. If No. 5 gives an additional yield the soil is in want of nitrogen. From the eight plots it will be possible to tell which of the various elements it will be advisable to use. The fertilizers should be applied after the land has been thoroughly prepared and before seeding. Corn is a good crop for the first trials. The number of plots may be increased by using well-prepared stable manure and gypsum on plots 9 and 10 respectively. The second year the results should be verified.

280. Deficiency of Nitrogen.—If the results indicate a deficiency of nitrogen, select two crops, one as wheat which is particularly benefited by dressings of nitrogen, and another as corn which has no difficulty in obtaining this element. The cultivation of each crop should be that which experience has shown to be the best. On one wheat, and one corn plot, 8 pounds of nitrate of soda should be used, a plot each of wheat and corn being left unfertilized. If both the corn and the wheat are benefited by the application of nitrogen, the soil is in need of available nitrogen. If, however, the wheat responds and the corn does not, the soil is not in great need of nitrogen but does not contain an abundance in available forms.

281. Deficiency of Phosphoric Acid. — In experimenting with phosphoric acid, turnips are grown on two plots and barley on two plots. To one plot of each 16 pounds of acid phosphate are applied. If both crops show marked additional yields the soil is in need of available phosphoric acid. If only the turnips respond while the barley is indifferent the soil contains a fair amount of available phosphoric acid. Barley and turnips are used because there is such a marked difference in the power of each to assimilate phosphoric acid.

282. Deficiency of Potash. — In order to determine the condition of the soil as to potash, potatoes and oats may be used as the trial crops, and 8 pounds of sulphate of potash should be applied to one plot of each. Marked additional yields indicate a poverty of available potash ; an increased potato crop and an indifferent oat crop indicate potash not in the most available forms. If no additional yields are obtained the soil is not in need of potash.

283. Deficiency of Two Elements. — If the preliminary trials indicate a deficiency of two elements as nitrogen and phosphoric acid, both elements are used together, in the same way as described for deficiency of nitrogen, with additional plots for the separate application of nitrogen and phosphoric acid.

284. Importance of Field Trials. — While it seems a troublesome matter to determine the actual needs of a soil, it will be found that both time and money are saved by a systematic study of the question. Suppose fertilizers are used in a "hit or miss" way year after year on a soil, deficient only in phosphoric acid. It would take 8 years to find out what the soil was deficient in, if a different fertilizer were used each year, and during all this period, either the soil has failed to receive its proper fertilizer, or expensive and unnecessary plant food has been provided.

285. Will it Pay to Use Commercial Fertilizers? — This question can be answered only by trial. If a soil is in need of available plant food, the additional amount of crop produced should pay for the fertilizer and the expense of using it. Some fertilizers have an influence on two or three succeeding crops, and only partial returns are received the first year. When large crops must be produced on small areas, as in truck farming, commercial fertilizers are generally necessary. In the production of large areas of staple crops as wheat and corn, in the western prairie states, they have never been used. If the soil is properly tilled and there is a good stock of natural fertility, the use of commercial fertilizers can be avoided. With poor cultivation and a soil that has been impoverished by injudicious cultivation their use is more necessary.

286. Amount of Fertilizer to Use per Acre. — When commercial fertilizers are used, it should be the aim to apply just enough to produce normal yields. Heavy applications at long intervals are not as productive of good results as light applications more frequently. From 400 to 600 pounds per acre is as much as should be used at one time unless previous trials have shown that heavier applications are necessary. The way in which the fertilizer is to be applied, as broadcast or otherwise, must be determined by the crop to be grown. The fertilizer should not come in direct contact with seeds, neither should it be worked into the soil to such a depth that it may be lost by leaching before it can be appropriated by the crop.

287. Excessive Applications of Fertilizers Injurious. — An overabundance of plant food has an injurious effect upon crop growth. Plants take their food from the soil in dilute solutions, and when the solution is concentrated abnormal growth results. Potatoes heavily manured with nitrate of soda make a luxuriant growth of vines but produce only a few small tubers. When a medium dressing is used along with potash and phosphoric acid, a more balanced growth is obtained, and a better yield is the result.

Heavy applications of nitrate of soda produce a rank growth of straw, with a low yield of grain. The excessive amount of nitrogen causes the mineral matter to be utilized for straw production and leaves only a small amount for grain production. When applications of commercial fertilizers are too heavy, plants take up unnecessary amounts of food and fail to make good use of it. In fact crops may be overfed the same as animals. Hence in the use of fertilizers excessive applications are to be avoided.

288. Fertilizing Special Crops. — There are crops which need special help in obtaining some one element, and in the use of fertilizers it should be the rule to help those crops which have the greatest difficulty in obtaining food. When the soil does not show a marked deficiency in any one element, light dressings of special purpose manures may be made to the following crops :

Wheat. — Nitrogen first ; phosphoric acid to a less extent.

Barley, oats, and rye require manuring like wheat, but to a less extent. Each crop has a different power of obtaining nitrogen. Wheat requires the most help and barley and rye the least.

Corn. — Phosphoric acid first ; then nitrogen and potash.

Potatoes. — General manuring; reenforced with potash.

Mangels. — Nitrogen.

Turnips. — Phosphoric acid.

Clover. — Lime and potash.

Timothy. — General manuring.

289. Commercial Fertilizers and Farm Manures. — Commercial fertilizers should not replace farm manures, but simply reenforce them. Although commercial fertilizers are called complete manures, they fail to supply organic matter. It is more important in some soils than in others, that the organic matter be maintained because in some soils the organic matter takes a more important part in crop production than does the food applied in commercial forms. For example, when a rich prairie soil is reduced by grain cropping and is allowed to return to pasture, heavier yields of grain are afterwards obtained than from similar soils which received applications of commercial fertilizers.

CHAPTER XI

FOOD REQUIREMENTS OF CROPS

290. Amount of Fertility Removed by Crops. — From an acre of soil, producing average crops, the amount of fertility removed varies between wide limits. For example, an acre of mangels removes 150 pounds of potash, while an acre of flax removes 27 pounds; an acre of corn removes about 75 pounds of nitrogen, while an acre of wheat removes about 35 pounds. Crops which remove the most fertility do not always require the most help in obtaining their food. This is because the amount of plant food assimilated, and the power of crops to obtain this food, are not the same. An acre of corn, for example, takes over twice as much nitrogen as an acre of wheat, but wheat will often leave the soil in a more impoverished condition than corn, because corn has greater power for procuring nitrogen and for utilizing that formed by nitrification after the wheat crop has completed its growth. The available nitrogen if not utilized by a crop may be lost in various ways. Mangels require about twice as much phosphoric acid as flax, but are a strong feeding crop and require less help in obtaining this element.

It was formerly believed that the amount of plant food present in the matured crop indicated the kind and amount of fertilizing ingredients to apply, and that a correct system of manuring required a return to the soil of all elements removed in the crop. Experiments have shown that both of these views are incorrect. The composition of plants cannot be taken as the basis for their manuring. For example an acre of wheat contains 35 pounds of nitrogen while an acre of clover contains 70 pounds. If 70 pounds of nitrogen were applied to an acre of clover and 35 pounds to an acre of wheat, poor results would follow, because clover can obtain its own nitrogen while wheat is nearly helpless in obtaining it, and the 35 pounds would not necessarily come in contact with the roots so that it could all be assimilated. While the amount of plant food removed in crops cannot serve as the basis for their manuring, valuable results are obtained from the study of the different elements of fertility removed in crops, and in making use of the following figures, other factors, as the influence of the crop upon the soil and the power of the crop to obtain its food, must also be considered.

PLANT FOOD REMOVED BY CROPS[37]

Crops.	Gross weight.	Nitrogen.	Phosphoric acid.	Potash.	Lime.	Silica.	Total ash.
		Pounds per acre.					
Wheat, 20 bus.....	1200	25	12.5	7	1	1	25
Straw	2000	10	7.5	28	7	115	185
Total	....	35	20	35	8	116	210
Barley, 40 bus.....	1920	28	15	8	1	12	40
Straw	3000	12	5	30	8	60	176
Total.........	....	40	20	38	9	72	216
Oats, 50 bus.......	1600	35	12	10	1.5	15	55
Straw	3000	15	6	35	9.5	60	150
Total	....	50	18	45	11.0	75	205
Corn, 65 bus	2200	40	18	15	1	1	40
Stalks............	3000	35	2	45	11	89	160
Total	....	75	20	60	12	90	200
Peas, 30 bus.......	1800	..	18	22	4	1	64
Straw	3500	..	7	38	71	9	176
Total	....	..	25	60	75	10	240
Mangels, 10 tons..	20000	75	35	150	30	10	350
Meadow hay, 1 ton	2000	30	20	45	12	50	175
Red Clover Hay, 2 tons........	4000	..	28	66	75	15	250
Potatoes, 150 bus..	9000	40	20	75	25	4	125
Flax, 15 bus	900	39	15	8	3	0.5	34
Straw	1800	15	3	19	13	3	53
Total	....	54	18	27	16	3.5	87

291. Plants Render Their Own Food Soluble. — It was supposed at one time that plants obtained all of their mineral food from the mineral matter dissolved in the soil water. Experiments by Liebig demonstrated that plants have the power of rendering their own food soluble, provided it does not exist in forms too inert to undergo chemical change. Liebig grew barley in boxes so constructed that all of the water-soluble plant food could be secured. Two of the boxes were manured and two left unmanured. In one box which received manure and one which received none, barley was grown. One each of the manured and unmanured boxes was left barren. He collected all of the drain waters and determined the soluble mineral matter present, also weighed and analyzed the crop. His results showed that 92 per cent. of the potash in the crop was obtained from forms insoluble in water.[72]

In the roots of all plants there are present various organic acids. Between the rootlet and the soil there is a layer of water. The plant sap and the soil water are separated by plant tissue which acts as a membrane. All of the conditions are favorable for osmosis. The acid sap from the roots finds its way into the soil in exchange for some of the soil water. This acid, excreted by the roots, acts upon the mineral matter, rendering it soluble, when it is taken up by the plant. Different plants contain different kinds and amounts of organic acids as well as present different areas of root surface to act upon the soil, and the result is that agricultural crops have different powers of assimilating food.

Plants not only possess the power of rendering their food soluble but they are also able to select their own food and to reject that which is unnecessary. For example, wheat grown on prairie soil containing soda in equally abundant and soluble forms as the potash, will contain relatively little soda compared with the potash in the crop.[36]

CEREAL CROPS

292. General Food Requirements. — Cereal crops contain a high per cent. of silica and evidently possess the power of feeding upon some of the simpler silicates of the soil,[73] liberating the base elements which are utilized as food, while the silica is deposited in the outer surface of the straw. As previously stated, cereal crops although they do not remove large amounts of total nitrogen from the soil require special help in obtaining this element. There is, however, a great difference among the cereals as to power of assimilating nitrogen. Next to nitrogen these crops stand most in need of phosphoric acid. The humic phosphates are utilized by nearly all of the cereals.

293. Wheat. — This crop is more exacting in its food requirements than barley, oats, or rye. Wheat is comparatively a weak feeding crop, and the soil should be in a higher state of fertility than for other grains. The extensive experiments of Lawes and Gilbert have given valuable information regarding the effects of manures on wheat. The results are given in the following table :[74]

AVERAGE YIELD OF WHEAT PER ACRE.

	Bushels.
No manure for 40 years	14
Minerals alone for 32 years	$15\frac{1}{4}$
Nitrogen " " " "	$23\frac{1}{2}$
Farmyard manure for 32 years	$32\frac{3}{8}$
Minerals and nitrogen for 32 years[1]	$36\frac{1}{4}$
" " " " " "[2]	$32\frac{3}{4}$

The food requirements of wheat are such that it should be given a favored position in the rotation. Wheat may follow clover provided the clover sod is light and is fall plowed. On some soils, however, wheat does not thrive following a sod crop. It takes nearly a year for a heavy sod residue to get into suitable food forms for a wheat crop. Under such conditions, oats should first be sown, then wheat may follow. On average soil a medium clover sod, plowed late in summer or in early fall, and followed with surface cultivation, leaves the land in good condition for spring wheat. It is not advisable to have wheat follow barley, because the soil will be too porous, and barley being a stronger feeding crop leaves the land in poor condition as to available plant food. When a corn crop is well manured, wheat may follow. The food requirements of wheat are best satisfied following a light, well cultivated clover sod, or following oats which have been grown on heavy sod, or following corn that has been well manured.

[1] 86 pounds of nitrogen as sodium nitrate.

[2] 86 " " " " ammonium salts.

294. Barley. — While wheat and barley belong to the same general class of cereals, they differ greatly in their habits and food requirements. Barley is a stronger feeding crop, has a greater root development near the surface, and can utilize food in cruder forms. In many of the western states, soils which produce poor wheat crops, from too long cultivation, give excellent yields of barley. This is due to changed conditions, of both the chemical and mechanical composition of the soil. Long cultivation has made the soil porous and reduced the nitrogen content. Barley thrives best on a rather open soil and has greater nitrogen assimilative powers than wheat. Barley, however, responds liberally to manuring, particularly to nitrogenous manures. The experiments of Lawes and Gilbert on the growth of barley are briefly summarized in the following table.[75]

Average Yield of Barley Per Acre for 34 Years.

	Bushels.
No manure	$17\frac{7}{8}$
Superphosphate alone	$23\frac{7}{8}$
Mixed minerals	$24\frac{1}{4}$
Nitrogen alone	$30\frac{3}{4}$
Nitrogen and superphosphate	45
Farmyard manures	$49\frac{1}{2}$

295. Oats. — Oats are capable of obtaining food under more adverse conditions than either barley or wheat. They are also less exacting as to soil requirements. The oat plant will adapt itself to either sandy or clay soil, and will thrive in the presence of alkaline matter or humic acid where wheat would be destroyed. In a rotation, oats usually occupy a position less favored by manures. They are, however, greatly benefited by fertilizers particularly by those of a nitrogenous nature.

296. Corn. — Experiments with corn indicate that under ordinary conditions it requires most help in obtaining phosphoric acid. Corn removes a large amount of gross fertility but its habits of growth are such that it generally leaves an average soil in better condition for succeeding crops. Corn is not injured as are many grain crops by heavy applications of stable manure. It does not, like flax, produce waste products which are destructive to itself. Rich prairie soils when newly broken give better results for wheat culture after one or two corn crops have been removed. The food requirements of corn are satisfied by applications of stable manure, occasionally reenforced with a little phosphoric acid. After clover, corn gives excellent returns, and when corn is the chief market crop it should be favored by having the best position in a rotation.

MISCELLANEOUS CROPS

297. Flax is very exacting in food requirements and for its culture the soil must be in a high state of fertility. It is a type of a weak feeding crop. There are but few roots near the surface and consequently it has restricted powers of nitrogen assimilation.[37] Flax does not remove a large amount of fertility but if grown too frequently the tendency is to get the land out of condition rather than to exhaust it. Flax should be indirectly manured. Direct applications of stable manure produce poor results, but when the manure is applied to the preceding crop excellent results are obtained. The best conditions for flax culture require that it should be grown on the same land only once in five years. Dr. Lugger has demonstrated that there are produced, when the roots and straw of flax decay, products which are destructive to succeeding flax crops.[76] The food requirements of flax are met when it follows corn which has been well manured, or a sod which has been given the cultivation described for wheat. Flax and spring wheat are much alike in food requirements.

298. Potatoes. — Potatoes are surface feeders and when grown continually upon the same soil without manure, the yield per acre decreases more rapidly than any other farm crop. Experiments with potatoes by Lawes and Gilbert using different manures gave the following result:[77]

AVERAGE YIELD PER ACRE FOR 12 YEARS.

	Tons.	Cwt.
No manure	1	$19\frac{3}{4}$
Superphosphate	3	5
Minerals alone	3	$7\frac{3}{4}$
Nitrate of soda alone	2	$4\frac{5}{8}$
Mixed manures and nitrogen	5	$17\frac{3}{8}$
Farm manures, alternate years	4	$3\frac{3}{4}$

Potatoes require liberal general manuring reenforced with wood ashes or other potash fertilizers. In the rotation they should follow grain or pasture land, provided the fertility of the soil is kept up.

299. Sugar-beets. — This crop is more exacting in its food demands than other root crop. Excessive fertility is not conducive to a high content of sugar. Soils in a medium state of fertility usually give the best results.[78] Sugar-beets should not receive heavy dressings of stable manure, because an abnormal growth results. Nitrogenous fertilizers can be applied only in limited amounts, heavier dressings of potash and phosphoric acid are more admissible. When sugar-beets follow corn which has been manured, or grain which has left the soil in an average state of fertility, the food requirements are well met.

300. Roots. — Mangels are gross feeders and remove a larger amount of fertility from the soil than any other farm crop.[73] When fed to stock and the manure is returned to the soil they materially aid in making the plant food more available for delicate feeding crops. Mangels are better able to obtain their phosphoric acid than are turnips and need the most help in the way of nitrogen. Turnips are surface feeders with stronger power of nitrogen assimilation than the grains but with restricted power of phosphate assimilation. Manures for turnips should be phosphatic in nature.

301. Rape is a type of a strong feeding plant capable of obtaining its food under conditions adverse to grain culture. When grown too frequently upon the same soil it does not thrive. On account of its great capacity for obtaining food, it is a valuable crop to use for green manuring purposes.[79]

302. Buckwheat is a strong feeding crop and its demands for food are easily met. On rich soil, a rank growth of straw results, with poor seed formation. Buckwheat is usually sown upon the poorest soil of the farm. Being a strong feeder it is frequently used as a manurial crop, being plowed under while green to serve as food for weaker feeding crops.

303. Cotton. — On average soils cotton stands in need first of phosphoric acid, second of nitrogen.[80] It is most able to obtain potash, but soils deficient in potash require its use. Organic nitrogen as cottonseed meal and stable manure appear equally as effective as nitric nitrogen. Phosphoric acid must be applied in the most available forms. In fertilizing cotton, the use of green manuring crops as cow peas with an application of marl gives beneficial results. Marl, however, should not be applied alone because of the formation of insoluble phosphate of lime. Lime combines with the decaying organic matter in preference to phosphates, a result which is beneficial to both soil and crop.

304. Hops. — The hop plant is peculiar in regard to its food requirements. An excess of easily soluble plant food is injurious while a lack is equally so. An abundance of food in organic forms is most essential. Heavy dressings of farm manures may be applied. Where hops are grown there is a tendency to use all of the manure on the hops while the rest of the farm is left unmanured. Very light applications of commercial fertilizers may be used in connection with stable manure, but such use should be made only after a preliminary trial on a smaller scale.

305. Hay and Grass Crops. — Most grass crops have shorter roots than grain crops; they are surface feeders and not so able to secure mineral food. When a number of crops have been removed the soil may stand in need of available mineral matter. Farm manures are particularly well adapted for fertilizing grass. Applications of nitrogenous manures result in discouraging the growth of clover. Heavy manuring of grass land has a tendency to reduce the number of species and one kind is apt to predominate.[81] On some soils ashes, and on others lime fertilizers, have been found very beneficial. The manuring of grass lands must be varied to meet the requirements of different soils. Permanent meadows require different manuring from meadow simply introduced as an important crop in the rotation.

306. Leguminous Crops. — For leguminous crops potash and lime fertilizers have been found of most value.

Analyses of leguminous crops, as clover and peas, show large amounts of both potash and lime. Many crops as clover fail when grown too frequently upon the same soil, not because the soil is exhausted but because of the development in the soil of organic products which are destructive to growth. When the inexpensive food requirements of leguminous crops are supplied, the soil is enriched with nitrogen and phosphoric acid which have been changed to more available forms.

CHAPTER XII

ROTATION OF CROPS AND CONSERVATION OF SOIL FERTILITY

307. Object of Crop Rotation. — The object of the systematic rotation of crops is to conserve the fertility of the soil, and at the same time to produce larger yields. In order to accomplish this, the food requirements of different crops must be met by good cultivation and proper manuring. Rotations must be planned according to the nature of the soil and the system of farming that is to be followed. For general grain farming a different system must be practiced than for exclusive dairying. Whatever the nature of farming the whole farm should gradually undergo a systematic rotation. If the farm is uneven in soil texture, different rotations must be practiced on the various parts. There is no way in which soils are more rapidly depleted of fertility than by the continued culture of one crop. In exclusive wheat raising for example the losses which occur are not confined to the fertility removed in the crop but may take place in other ways as described in the chapter on nitrogen. When wheat is properly grown in alternation with other crops, losses of nitrogen are reduced to the minimum.

When remunerative crops can no longer be produced the soil is said to be exhausted. Soil exhaustion may be due either to a lack of fertility or to getting the soil out of condition because of the "one-crop system" and poor methods of cultivation.

308. Principles Involved in Crop Rotation. — In the systematic rotation of crops there are a few fundamental principles with which all rotations should be made to conform. Briefly stated these principles are:

1. Deep and shallow rooted crops should alternate.
2. Humus-consuming and humus-producing crops should alternate.
3. Crops should be rotated so as to make the best use of the preceding crop residue.
4. Crops should be rotated so as to secure nitrogen indirectly from atmospheric sources.
5. Crops should be rotated so as to keep the soil in the best mechanical condition.
6. In arid regions crops should be rotated so as to make the best use of the soil water.
7. An even distribution of farm labor should be secured by a rotation.
8. Farm manures and fertilizers should be used in the rotation where they will do the most good.
9. Rotations should be planned so as to produce fodder for stock, and so that every year there will be some important crop to be sold.

309. Deep and Shallow Rooted Crops. — When deep and shallow rooted crops alternate, the draft upon the surface soil and subsoil is more evenly distributed.

In many soils nitrogen and phosphoric acid are more abundant in the surface soil while potash and lime predominate in the subsoil. When such a condition exists, the alternating of deep and shallow rooted crops is very beneficial, because the surface soil is relieved of continuous heavy drafts upon the elements present in scant amounts.

310. Humus-consuming and Humus-producing Crops. — When grain or hoed crops are grown continuously, oxidation of the humus occurs, and the chemical and physical properties of the soil may be entirely changed by the loss of the humus. The rotating of grass and grain crops and the use of stable manure serve to maintain the humus equilibrium. On some soils lime may be required along with the humus to prevent the formation of humic acid, and in such cases the best conditions exist when both lime and humus materials are supplied. The alternation of humus-producing and humus-consuming crops is one of the essential matters to consider in a rotation.

311. Crop Residue. — Crop residues should always be placed at the disposal of weak feeding crops. For example, after a light clover and timothy sod, wheat or flax should be grown in preference to barley or mangels. The weak feeding crop should then be followed by a strong feeding crop, and each is properly supplied with food. It would be poor economy, on an average soil, to follow clover and timothy with mangels, then with barley, and finally with flax, because the flax would be placed at a serious disadvantage following two strong feeding crops. If reversed, the crops would be placed in order of assimilative power, and the best use would be made of the sod crop residue. When crops of dissimilar feeding habits follow each other in rotation not only are the crop residues used to the best advantage, but the soil is relieved of excessive demands on special elements. For example, wheat and clover take different amounts of potash and lime from the soil. Wheat has the power of feeding upon silicates of potash which clover cannot assimilate, hence wheat and clover in rotation relieve the soil of excessive demands on the potash.

312. Nitrogen-consuming and Nitrogen-producing Crops. — It is possible in a five-course rotation to maintain or even increase the nitrogen of the soil without the use of nitrogenous manures. In Section **131** an example is given of a rotation which has left the soil with a better supply of nitrogen than at the beginning. When a soil produces a good clover crop once in five years, and stable manure is used once during the rotation, the soil nitrogen is not decreased. By means of rotating nitrogen-producing and nitrogen-consuming crops it is possible to sell nitrogenous grain products from the farm without purchasing nitrogenous manures. The conservation of the nitrogen of the soil is the most important point to consider in the rotation of crops, because it is the most expensive element and is the most liable to be deficient.

313. Influence of Rotation upon the Mechanical Condition of Soils. — With different kinds of crops, the mechanical conditions of soils are constantly undergoing change. Grain crops and hoed crops tend to make the soil open in texture. Grass crops have the opposite effect. All soils should undergo periodic compacting and loosening. Some require more of one treatment than of the other. In a good rotation the mechanical action of the crop upon the soil should be considered, otherwise the soil may get into poor condition to retain water or become so loose that heavy losses occur through wind storms. Sandy soils are improved by those methods of cropping which compact the soil, while heavy clays require the opposite treatment. The rotation should be made to conform to the requirements of the soil.

314. Economic Use of Soil Water. — The rotation should not be of such a nature as to make excessive demands upon the soil water. For example, after a grain crop has been produced, it is best in regions of scant rainfall to plow the land and get it into condition to conserve the water for the next year's crop, rather than to attempt to raise a catch crop the same year. Crops removing excessive amounts of water should not be grown too frequently. Sunflowers, for example, remove twenty times more water than grain crops. Cabbage removes from the soil more water than many other crops. With a good rotation it is possible to carry the water balance in the soil from year to year, so that crops will be supplied in times of drought.

315. Rotation and Farm Labor. — The rotation of crops should be planned so that an even distribution of farm labor is secured. The importance of this principle is so plain that its discussion is unnecessary. It is a topic outside of the domain of chemistry, but is nevertheless one of the most important to consider in economic farming, and should not be lost sight of in planning rotations.

316. Economic Use of Manures. — Farm manure should be applied to those crops which experience has shown to be the most benefited by its use. At least once during a five years' rotation the land should receive a dressing of stable manure. If commercial fertilizers are used, they should be applied to the crops which require the most help in obtaining food. With the growing of clover and the use of farm manures, only the poorer kinds of soil will require commercial fertilizers for general crop production. It is more economical to reenforce the farm manures with fertilizers especially adapted to the soil and crop than to purchase complete fertilizers.

317. Salable Crops.— In all farming, something must be sold from the farm. It should be the aim to sell products which remove the least fertility, or if those are sold which remove large amounts, to return in cheaper forms the fertility sold. In a good rotation it is the plan to have at least one salable crop each year. The whole farm need not undergo the same rotation at the same time and the rotation may be subject to minor changes as circumstances require. To illustrate, wheat and flax occupy about the same position in a rotation. If when the crop is to be seeded the indications are that wheat will be a poor paying crop and flax sell well, flax should be sown. The rotation should be such that one of two or three crops may be grown as circumstances require.

318. Rotations Advantageous in Other Ways. — A good rotation will be found advantageous in many ways. With one line of cropping, land becomes foul with special kinds of weeds which are unable to thrive when crops are rotated. Frequently the rotation must be planned so as to reclaim the land from weeds.

Relief from insect pests is often secured by a proper rotation. Many insects are capable of living only on a special crop and when this crop is grown continually on the same land the best conditions for insect ravages exist.

319. Long- and Short-course Rotations. — Rotations vary in length from 2 to 17 years. Long-course rotations are more generally followed in European countries. The length of the rotation can only be determined by the conditions existing in different localities. As a general rule long-course rotations should be attempted only after a careful study of all the conditions relating to the system of farming that it is desired to follow. For northern latitudes a rotation of four or five years gives excellent results. In some localities three-course rotations are the most desirable.

A rotation that is suitable for one locality or kind of farming may be unsuited for other localities or conditions. Because of variations in soil, climate, and rainfall, no definite standard rotation can be proposed that will be suitable for all conditions.

320. Example of Rotation. — In dealing with the subject of rotations it is best to take actual problems as they present themselves and plan rotations that will best meet all conditions. For example, a farm of 160 acres is to be rotated with the main object of producing fodder for live stock, and a small amount of grain for sale. The following rotation has been proposed to meet such conditions.[82]

Rotation for Dairy Farm.

	1.	2.	3.	4.
1st year	Corn (manured).	Pasture.	Meadow.	Oats (clover and timothy).
2nd year	One-half wheat, one-half flax.	Corn (manured).	Pasture.	Meadow.
3rd year	Barley (manured).	One-half wheat, one-half flax.	Corn (manured).	Pasture.
4th year	One-fourth potatoes, one-fourth peas, one-fourth rye, one-fourth corn fodder.	Barley.	One-half wheat, one-half flax.	Corn (manured).
5th year	Oats (clover and timothy).	One-fourth potatoes and roots, one-fourth peas, one-fourth rye, one-fourth corn fodder.	Barley.	One-half wheat, one-half flax.
6th year	Meadow.	Oats (clover and timothy).	One-fourth potatoes and roots, one fourth peas, one-fourth rye, one-fourth corn fodder.	Barley.
7th year	Pasture.	Meadow.	Oats (clover and timothy).	One-fourth potatoes, one-fourth peas, one-fourth rye, one-fourth corn fodder.

Rotation for Dairy Farm.

	5	6	7	8
1st year	One-half wheat, one-half flax.	Barley (manured).	One-fourth potatoes, one-fourth rye, one-fourth peas, one-fourth corn fodder,	Reserved for miscellaneous crops.
2nd year	Barley (manured).	One-fourth potatoes, one-fourth rye, one-fourth peas, one-fourth corn fodder.	Oats (clover and timothy).	
3rd year	One-fourth potatoes, one-fourth rye, one-fourth peas, one-fourth corn fodder.	Oats (clover and timothy).	Meadow.	
4th year	Oats (clover and timothy).	Meadow.	Pasture.	
5th year	Meadow.	Pasture.	Corn (manured).	
6th year	Pasture.	Corn (manured).	One-half wheat, one-half flax.	
7th year	Corn (manured).	One-half wheat, one-half flax.	Barley (manured).	

The farm is divided into eight fields of 20 acres each; seven fields are brought under the rotation, while one field is left free for miscellaneous purposes. Each year there are produced 20 acres of corn, 20 acres of timothy and clover hay, 10 acres each of wheat and flax, 20 acres of barley, and five acres each of corn fodder, rye, peas, and potatoes, while 20 acres are reserved for pasture. The main income is derived from the sale of live stock and dairy products.

Problems on Rotations

1. Plan a rotation for general farming (160 acres), using the following crops: clover, timothy, barley, oats, potatoes, and corn. The soil is in an average state of fertility. Twenty-five head of stock are kept.

2. Plan a three-course rotation for a sandy soil, the main object being potato culture.

3. Plan a seven-year rotation for grain farming, using manure and sodium nitrate once during the rotation. The soil is a clay loam in a good state of fertility.

4. Plan a rotation for general farming on a sandy loam.

5. How would you proceed to bring an old grain farm from a low to a high state of productiveness? Begin with the feeding of the stock.

6. Using commercial and special-purpose manures, how would you proceed to raise wheat, potatoes, and hay, each continuously?

7. Plan a rotation for a northern latitude, where corn cannot be grown, and where clover and timothy fail to do well; wheat and all small grains thrive; also millet, peas, rape, and some of the root crops. The soil is a clay loam, resting on a marl subsoil. Manure is very slow in decomposing. The rotation should be suited to general farming, wheat being the important market crop.

321. Manures Necessary for Conservation of Fertility. — In order to conserve the fertility of the soil, not only must a systematic rotation be practiced, but a proper use must be made of the crops produced. When they are sold from the farm and no restoration is made soils are gradually depleted of their fertility. No soil has ever been found that will continue to produce crops without the use of manures. Many prairie soils give large yields for long periods without manuring, but they are never able to compete in productiveness with similar soils that have been systematically cropped and manured. With a fertile soil the decline of fertility is so gradual that it is not observed unless careful records are kept of the yields from year to year.

322. Use of Crops.— The use made of crops whether as food for stock or sold directly from the farm, determines the future crop-producing power of the soil. With different systems of farming different uses are made of crops. When exclusive grain farming is followed no restoration of fertility is made, while in the case of stock farming, the manure produced contains fertility in proportion to the crops consumed. If good care is taken of the manure, and in place of the grains sold, mill products are purchased and fed, there is no loss of fertility. Between these two extremes, exclusive grain farming and stock farming, there are found in actual practice, different systems of farming, which remove various amounts of fertility from the soil.

323. Two Systems of Farming Compared.— The losses of fertility from farms are determined by the crops and products sold, the care of the manure, and the fertility in the products purchased and used on the farm. If an account were kept of the income and outgo of the fertility of farms it would be found that with some systems, the soil is gaining in fertility, while with others a rapid decline occurs. In studying the income and outgo of fertility, it is necessary to calculate the amount of the three principal elements, nitrogen, phosphoric acid, and potash in the crops and products sold. For making these calculations tables are given in Sections **178** and **290.** In the handling of manure it is impossible to prevent losses, but it is possible to reduce them to very small amounts. Hence in the calculations, a loss of 3 per cent. is allowed for mechanical waste, and for uneven distribution of the manure; that is, in addition to the fertility sold from the farm a loss of 3 per cent. is allowed for all crops raised and consumed as food by stock.

On one farm the crops raised and sold are: Flax 40 acres, wheat 50 acres, oats 20 acres, barley 50 acres; no stock is kept, the straw is burned, and the ashes are wasted.

EXCLUSIVE GRAIN FARMING.

Sold from the Farm

	Nitrogen. Pounds.	Phosphoric acid. Pounds.	Potash. Pounds.
Flax, 40 acres	1600	600	800
Flax straw	600	120	320
Wheat, 50 acres	1250	625	350
Wheat straw	500	375	1400
Oats, 20 acres	700	240	200
Oat straw	300	120	700
Barley, 50 acres	1400	750	400
Barley straw	600	250	1500
Total	6950	3080	5670

In addition to the nitrogen removed in the crops other losses must be considered. Experiments have shown that when exclusive grain farming is practiced, for every pound of nitrogen removed in the crop, four pounds are lost from the soil in other ways. This would make the total loss of nitrogen over 28,500 pounds or 177 pounds per acre, which large as it may seem is the actual loss from the soil when grain only is raised and sold. Experiments at the Minnesota Experiment Station have shown that after a soil had been cultivated 40 years, the annual loss per acre of nitrogen in exclusive wheat raising was 25 pounds through the crop and 146 pounds due to the oxidation of the nitrogenous humus of the soil.[17]

When exclusive grain farming is followed, the annual losses of fertility from a farm of 160 acres are 28,500 pounds of nitrogen, 3000 pounds of phosphoric acid, and 5500 pounds of potash.

On a similar farm of 160 acres the crops are rotated as described in Section **320**. The amounts of fertility in the products sold, the crops raised and consumed as fodder, and the food and fuel purchased, are given in the following table:

Stock Farming

Sold from the Farm

	Nitrogen. Pounds.	Phosphoric acid. Pounds.	Potash. Pounds.
Butter, 5000 pounds	5	5	5
Young cattle, 10 head	200	190	16
Hogs, 20 of 250 pounds each	100	40	10
Steers, 2	48	38	4
Wheat, 10 acres	250	125	70
Flax, 10 acres	390	150	190
Rye, 10 acres	285	128	85
Total	1278	676	380

Raised and Consumed on the Farm

Clover, 20 tons	66	270	600
Timothy, 20 tons	600	180	800
Corn, 20 acres	1500	300	800
Corn fodder, 1 acre	75	15	60
Mangels, 2 acres	150	70	300
Potatoes, 1 acre	40	20	75
Straw, 40 tons	400	200	1000
Peas, 5 acres	...	85	200
Oats, 20 acres	700	240	200
Barley, 20 acres with straw	800	400	760
	4265	1780	4795
Mechanical loss of food consumed, 3 per cent	128	53	144

Food and Fuel Purchased

	Nitrogen. Pounds.	Phosphoric acid. Pounds.	Potash. Pounds.
Bran, 5 tons	275	260	150
Shorts, 5 tons	250	150	100
Oil meal, 2 tons	100	35	25
Hard-wood ashes	...	25	100
	625	470	375
Sold from farm	1278	676	380
Loss in food consumed, etc	128	53	144
Total	1406	729	524
Food and fuel purchased	625	470	375
Balance lost from farm	781	259	149

The manure produced and used on this farm results in the production of larger crop yields than is the case with exclusive grain culture. The clover and peas more than balance the loss of nitrogen. Experiments have shown that a rotation similar to this caused an increase in soil nitrogen. Manure, meadow and pasture all tend to increase the soil humus and nitrogen. The losses of phosphoric acid and potash are exceedingly small, averaging less than a pound per acre of each. The action of manure on this farm is continually bringing into activity the inert plant food of the soil so that every year there is a larger amount of active plant food, which results in producing larger yields per acre.

The increase or decrease of fertility on farms has a marked effect upon crop yields. For example the average yield of wheat in those counties in Minnesota where live stock is kept, is 7 bushels per acre greater than in similar counties where all grain farming is followed.

Problems

Calculate the income and outgo of fertility from the following farms:

1. Sold from the farm: wheat 40 acres, oats 40 acres, barley 40 acres, rye 20 acres, flax 10 acres. The straw is burned and no use is made of any manures.

2. Sold from the farm: wheat 20 acres, barley 20 acres, flax 5 acres, 1000 pounds of butter, 10 hogs, and 10 steers. Purchased: Bran 3 tons, shorts 2 tons, oil meal 1 ton. Crops produced and fed on farm: Clover and timothy hay 40 tons, corn fodder 3 acres, corn 10 acres, oats and peas 10 acres, roots 1 acre, millet 1 acre, and barley 5 acres.

3. Sold from the farm: Wheat 10 acres, sugar beets 5 acres, milk 100,000 pounds, butter 500 pounds, 20 pigs, 6 head of young stock, 2 acres of potatoes. Purchased: 5 tons of bran, 2 tons of oil meal, 1 ton of cottonseed meal, 15 cords of wood, 1 ton of acid phosphate, 1000 pounds of potassium sulphate, and 500 pounds of sodium nitrate. Raised and consumed on the farm: Corn fodder 15 acres, mangels 1 acre, peas and oats 5 acres, clover 20 tons, timothy 10 tons, straw from grain sold, oats, 10 acres, corn 20 acres.

REFERENCES

1. Venable : History of Chemistry.

2. Gilbert : Inaugural Lecture, University of Oxford.

3. Liebig : Chemistry in Its Applications to Agriculture and Physiology.

4. Gilbert : The Scientific Principles of Agriculture (Lecture).

5. Minnesota Agricultural Experiment Station, Bulletin No. 30.

6. Stockbridge : Rocks and Soils.

7. Association of Official Agricultural Chemists, Report 1898.

NOTE : — This sentence should read : A division has recently been suggested by Hopkins in which the *square root of ten is* taken as the constant ratio between the grade of soil particles.

8. Maryland Agricultural Experiment Station, Bulletin No. 21.

9. Osborne : Journal of Analytical Chemistry, Vol. II, Part 3.

10. Wiley : Agricultural Analysis, Vol. I.

11. Hellriegel : Calculated from Beitrage zu den Naturwissenschaft Grandlagen des Ackerbaus.

12. King : Wisconsin Agricultural Experiment Station, Report 1889.

13. Unpublished results of author.

14. King : Soils.

15. Roberts : Fertility of the Land.

16. Minnesota Agricultural Experiment Station, Bulletin No. 41.

17. Minnesota Agricultural Experiment Station, Bulletin No. 53.

18. Whitney : Division of Soils, U. S. Department of Agriculture, Bulletin No. 6.

19. Merrill : Rocks, Rock-weathering and Soils.

20. Müntz : Comptes Rendus de l'Academie des Sciences, CX (1890).

21. Storer : Agriculture, Vol. I.

22. Dyer : Journal of the Chemical Society, March, 1894.

23. Goss : Association of Official Agricultural Chemists, Report 1896.

24. Peter: Association of Official Agricultural Chemists, Report 1895.

25. Loughridge: American Journal of Science, Vol. VII (1874).

26. Hilgard: Year-book U. S. Department of Agriculture, 1895.

27. Houston: Indiana Agricultural Experiment Station, Bulletin No. 46.

28. Mülder: From Mayer: Lehrbuch der Agrikulturchemie, 2.

29. Journal of the American Chemical Society, Vol. XIX, No. 9.

30. Year-book U. S. Department Agriculture, 1895.

31. Loughridge: South Carolina Agricultural Experiment Station, Second Annual Report.

32. Association of Official Agricultural Chemists, Report 1893.

33. Washington Agricultural Experiment Station, Bulletin No. 13.

34. Association of Official Agricultural Chemists, Report 1894.

35. California Agricultural Experiment Station, Report 1890.

36. Minnesota Agricultural Experiment Station, Bulletin No. 29.

37. Minnesota Agricultural Experiment Station, Bulletin No. 47.

38. Lawes and Gilbert: Experiments on Vegetation, Vol. I.

39. Boussingault: Agronomie, Tome I.

40. Atwater: American Chemical Journal, Vol. VI, No. 8 and Vol. VIII, No. 5.

41. Hellriegel: Welche Stickstoff Quellen stehen der Pflanze zu Gebote?

42. Minnesota Agricultural Experiment Station, Bulletin No. 34.

43. Warington: U. S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 8.

44. Hilgard: Association of Official Agricultural Chemists, Report 1895.

45. Marchal: Journal of the Chemical Society (abstract), June, 1894.

46. Künnemann: Die Landwirthschaftlichen Versuchs-Stationen, 50 (1898).

47. Adametz: Abstract, Biedermann's Centralblatt für Agrikulturchemie, 1887.

48. Atwater: American Chemical Journal, Vol. IX (1887).

49. Stutzer: Biedermann's Centralblatt für Agriculturchemie, 1883.

50. Jenkins: Connecticut State Agricultural Experiment Station, Report 1893.

51. Wagner: Biedermann's Centralblatt für Agrikulturchemie, 1897.

52. Journal of the Royal Agricultural Society, 1850.

53. From Sachsse: Lehrbuch der Agrikulturchemie.

54. Lawes and Gilbert: Experiments with Animals.

55. Beal: U. S. Department of Agriculture, Farmers' Bulletin No. 21.

56. Minnesota Agricultural Experiment Station, Bulletin No. 26.

57. Mainly from Armsby: Pennsylvania Agricultural Experiment Station, Report 1890. Figures for grains calculated from original data.

58. Heiden: Dungelehre.

59. Liebig: Natural Laws of Husbandry.

60. Cornell University Agricultural Experiment Station, Bulletins Nos. 13, 27, and 56.

61. Kinnard: From Manures and Manuring by Aikman.

62. Wyatt: Phosphates of America.

63. Wiley: Agricultural Analysis, Vol. III.

64. Goessmann: Massachusetts Agricultural Experiment Station, Report 1894.

65. Connecticut (State) Agricultural Experiment Station, Bulletin No. 103.

66. Goessmann: Massachusetts Agricultural Experiment Station, Report 1896.

67. Wheeler: Rhode Island Agricultural Experiment Station, Reports 1892, 1893, etc.

68. Boussingault: From Storer: Agriculture.

69. Handbook of Experiment Station Work.

70. New York (State) Agricultural Experiment Station, Bulletin No. 108.

71. Voorhees: U. S. Department of Agriculture, Farmers' Bulletin No. 44.

72. Liebig: Die Chemie in ihrer Anwendung auf Agrikultur und Physiologie.

73. Warington: Chemistry of the Farm.

74. Lawes and Gilbert: Growth of Wheat.

75. Lawes and Gilbert: Growth of Barley.

76. Lugger: Minnesota Agricultural Experiment Station, Bulletin No. 13.

77. Lawes and Gilbert: Growth of Potatoes.

78. Minnesota Agricultural Experiment Station, Bulletin No. 56.

79. Shaw: U. S. Department of Agriculture, Farmers' Bulletin No. 11.

80. White: U. S. Department of Agriculture, Farmers' Bulletin No. 48.

81. Lawes and Gilbert: Permanent Meadows.

82. Thompson: Graduating Essay, Minnesota School of Agriculture.

83. Nefedor: Abstract, Experiment Station Record, Vol. X, No. 4.

EXPERIMENTS

1. **Pulverized Rock and Soil.** — Pulverize in an iron mortar, pieces of feldspar, mica, granite, and limestone. Examine each with a lens. Finally mix all of the pulverized material, and compare the mixture with samples of soil.

2. **Weight of Soils.** — Weigh a cubic foot of air-dried sand, clay, and peat. For this purpose use a box holding ¼ of a cubic foot of soil. Do not compact the soil.

3. **Form of Soil Particles.** — Examine under a microscope soil particles and distinguish the various grades of sand and silt. Observe the form of the soil particles and make drawings of them.

4. **Separation of Soil Particles.** — By means of sieves, with holes, 1, ½, and ¼ mm. in diameter, separate these three grades of particles as described in Section 10. To what type does the soil examined belong?

5. **Capillarity.** — Place small glass tubes of various sizes in a vessel of water and note the height to which water rises by capillarity.

6. **Capillarity of Soils.** — Fill glass tubes 2 inches in diameter with clay and fine sand, respectively. Support the tubes so that one end will touch the water in a cylinder. Observe the rate and height to which the capillary water rises, making daily measurements for a week.

7. **Hydroscopic Moisture.** — Place 5 grams of air-dried soil on a watch-glass, in a water-oven, and after two hours reweigh and determine the loss of weight. Calculate the per cent. of hydroscopic moisture.

8. **Influence of Cultivation on Soil Water.** — Fill four boxes, each a foot square and a foot deep, with air-dried loam soil. Weigh the boxes and soil used. Each box is to be treated separately as follows : Measure one-half gallon of water into a watering-pot. Allow the water from the watering-pot to flow on the soil, regulating the flow so that it is all absorbed. The soil should be saturated, but

there should be no dripping. Measure or weigh any water left in the watering-pot. One box is to receive shallow surface cultivation, using for the purpose a small gardener's tool. Another box is to be left without receiving any treatment. The third is to receive treatment imitating that of the disk harrow, having the disks set perpendicularly. A sharp knife may be used for this purpose. In the fourth box the disk cuttings are to be made at an angle. Leave each box exposed to the sun or in a heated room, and determine the loss of weight every day for a week. From the loss of weight, determine the per cent. of water lost and the per cent. left in the soil.

9. **Capacity of Soil to Absorb Water.** — Weigh 100 grams of dry soil. Fit a medium-sized filter-paper in a funnel. Moisten the paper so that it will not absorb any more water. Then place the soil in the filter and add slowly from a beaker, containing exactly 100 cc. of water, enough to thoroughly saturate the soil. Collect all of the drippings from the funnel. Measure the drippings and the unused water in the beaker. Calculate the per cent. of water absorbed by the soil.

10. **Capacity of Sand for Holding Water.** — Repeat Experiment 9, using sand.

11. **The Influence of Manure upon the Water-holding Power of Soil.** — Repeat Experiment 9, using 95 grams of sand and 5 grams of dry and finely pulverized manure. The sand and manure should be thoroughly mixed before performing the experiment.

12. **Action of Heat upon Soils.** — Expose to the sun's rays samples of dry clay, peat, and sand; after two hours' exposure, obtain the temperature of each. The bulb of the thermometer is simply covered with soil. All of the observations should be made under similar conditions.

13. **Influence of Manure upon Soil Temperature.** — Expose to the sun's rays, moist clay soil, and mixed clay and fresh horse manure. After two hours observe the temperature of each.

14. **Odor and Taste of Soils.** — Observe the odor of dry, peaty soil that has been kept in a corked bottle. Note the taste of

peaty and of alkaline soils; test each with moistened litmus paper.

15. **Absorption of Gases.** — Put 50 grams of soil into a wide-mouthed bottle, add 50 cc. of water and 1 cc. strong ammonia. Note the odor. Cork the bottle, shake, and after twenty-four hours again observe the odor.

16. **Insoluble and Soluble Products of Soil.** — Digest in a covered beaker 10 grams of soil with 100 cc. hydrochloric acid (50 cc. strong hydrochloric acid and 50 cc. water). After two hours' digestion, cool and filter, using 25 cc. water to wash the acid from the insoluble residue. Note the quantity and appearance of the insoluble matter. To one-half the filtrate add ammonia until alkaline. What is the precipitate? Remove it by filtering, and to this second filtrate add ammonium oxalate. What is the precipitate? Evaporate the remainder of the original filtrate nearly to dryness. Add 20 cc. water, 3 cc. nitric acid, and 5 cc. of ammonium molybdate. After shaking the test-tube containing the mixture, it is placed in a beaker of water and heated to about 65° C. What is the yellow precipitate?

17. **Testing Soils for Combined Carbon Dioxide.**—One gram of soil is placed in a test-tube (Fig. 35) and 5 cc. of water and 3 cc. of hydrochloric acid added. A small looped tube *a*, containing a drop of lime-water, is then inserted into the test-tube. The test-tube is warmed. Observe the precipitate formed in the loop. What is it?

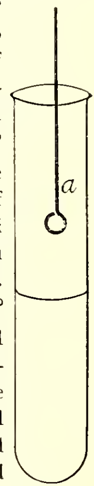


Fig. 35.

18. **Humus from Soils.** — Five grams of soil are placed in a glass-stoppered bottle, 100 cc. water and 3 cc. hydrochloric acid added. After shaking, the contents of the bottle are left twenty-four hours to subside. The acid is then poured off and 100 cc. of water added. The soil is left until the next day, when the water is poured off and 100 cc. of water and 5 cc. of ammonia are added. After shaking and allowing a little time for the soil to settle, the ammonia solution is filtered off.

To a portion of the filtrate add hydrochloric acid until the solution is just acid. Observe the precipitate. Evaporate another portion of the solution to dryness. What is the black residue?

19. **The nitrogen of soils.** — Place in a strong test-tube a mixture of 5 grams of soil and an equal bulk of soda-lime. Connect the test-tube with a delivery-tube which leads into another test-tube containing distilled water. Heat the test-tube containing the soil for five or ten minutes. Then test with litmus paper the liquid in the second test-tube, neutralize with standard acid as in Experiment **30**.

20. **Nitrates.** — Examine laboratory samples of the following nitrates: Potassium, calcium, and sodium. Place in separate test-tubes ½ gram of each, add 10 cc. of water, and heat gently. To each when cool add a few drops of sulphuric acid, then a few drops of an indigo solution.

21. **The Nitrogen of Blood.** — Repeat Experiment **19**, using 100 milligrams of dried blood in place of the soil.

22. **Organic Nitrogen Soluble in Pepsin.** — Prepare a pepsin solution by dissolving 5 grams of commercial pepsin in a liter of water, adding 1 cc. of strong hydrochloric acid. Place in separate test-tubes 5 grams each of dried blood, tankage, and horn meal. Add 25 cc. of pepsin solution and place the test-tubes in a cylinder containing water at a temperature of 40° C. Shake the test-tubes occasionally, and at the end of one-, two-, and five-hour periods observe the amounts of insoluble matter remaining in the test-tubes.

23. **Testing for Nitrates.** — Dissolve some sodium nitrate, not exceeding 100 milligrams, in 10 cc. water. Add 2 cc. of a dilute solution of ferrous sulphate, and place the test-tube in a cylinder of water. Sulphuric acid is then added by means of a long stemmed funnel. Observe the dark ring formed.

24. **Water in Manure.** — Dry 100 grams of fresh manure in a water-oven for four hours. Determine the loss of weight and the per cent. of water.

25. **Leaching Manure.** — Place 5 kilos of manure, the same as used in Experiment **24**, in a box provided with small holes in the bottom, so that the manure can be leached. Place the box over a sink or a receptacle for receiving the leachings. Percolate 3 gallons of water through the manure, daily, for five days. Finally weigh the manure, determine the per cent. of water, and the total loss of dry matter.

26. Volatilizing Ammonium Salts. — In separate test-tubes place about 100 milligrams each of ammonium carbonate and ammonium sulphate. Apply heat gently and observe the results. Place a cold glass rod in the test-tube when the white fumes are being given off.

27. Testing for Phosphoric Acid. — Dissolve a small piece of bone (5 grams) in 20 cc. nitric acid (10 cc. strong nitric acid and 10 cc. water). Filter. To the filtrate add 3 cc. of ammonium molybdate, warm, and shake. In a second test-tube dissolve 100 milligrams of sodium phosphate in 10 cc. water and add 3 cc. ammonium molybdate. Compare the result with that obtained with the bone.

28. Testing for Water-soluble and Acid-soluble Phosphates. — Place 1 gram of tricalcium phosphate in a test-tube with 10 cc. water. Boil. Filter through a close filter. To the filtrate add 3 cc. of ammonium molybdate. Repeat the experiment, using dilute nitric acid in place of water. Repeat the experiment, using monocalcium phosphate and water.

29. Preparation of Acid Phosphate. — Place 100 grams of powdered tricalcium phosphate in a large lead dish. Add slowly and with constant stirring 100 grams of commercial sulphuric acid, using an iron spatula for the purpose. Transfer the mixture to a wooden box and allow it to act for about three days. Then pulverize and examine. The material is saved for Experiment **34**. The mixing of the acid and phosphate should be done in a place where there is a good draft.

30. Testing Ashes. — Test samples of leached and of unleached ashes in the way described in Section **240**.

31. Flocculation of Clay. — Ten grams of clay soil are placed in a tall beaker or cylinder, 1000 cc. of water added, and the material triturated. The water containing the suspended clay is divided into two portions. To one portion 1 gram of calcium carbonate is added and the mixture stirred. After two or three hours compare the two portions.

32. Action of Lime on Acid Soil. — In a flask place 100 grams of acid peaty soil, add 5 grams of recently slaked lime and 200 cc. water; connect the flask by means of a delivery-tube with a wash-bottle containing lime-water and observe the results.

33. Marl. — Test a sample of marl for lime and carbon dioxide, as directed in Experiments **16** and **17**. Observe the nature of the insoluble residue. Test the marl with litmus paper.

34. Testing Land Plaster. — Test for carbon dioxide as directed in Experiment **17**. There should be but little carbon dioxide in the best grades of land plaster. Digest 1 gram of gypsum in a test-tube with 10 cc. dilute hydrochloric acid. Observe the nature and the amount of insoluble matter.

35. Mixing Fertilizers. — Mix in a large box

200 grams acid phosphate (saved from **28**),
50 grams kainit,
50 grams sodium nitrate.

Calculate the approximate composition of this fertilizer and its trade value.

36. Testing Fertilizers. — Test the above fertilizer for water-soluble phosphoric acid, as directed in Experiment **27**. Test for nitrogen pentoxide, as directed in Experiment **19**.

37. Calculating Results. — A fertilizer is said to contain 3.1 per cent. ammonia, 12 per cent. bone phosphate of lime and 6 per cent. potassium sulphate; calculate the equivalent amounts of nitrogen, phosphoric acid, and potash.

REVIEW QUESTIONS

1. From what are soils derived? 2. What are the physical properties of soils? 3. Why do soils differ in weight? Arrange clay, sand, loam, and peat in order of weight per cubic foot. 4. When wet, what would be the order? 5. What is the absolute and what the apparent specific gravity of soils? 6. Define the terms: Skeleton, fine earth, fine sand, silt, and clay. 7. What are the physical properties of clay? 8. What are the forms of the soil particles? 9. How do different types of soil vary as to the number of soil particles per gram of soil? 10. How is a mechanical analysis of a soil made? 11. Why do certain crops thrive best on definite types of soil? 12. What factors must be taken into consideration in determining the type to which a soil belongs? 13. Explain the mechanical structure of a good potato soil. 14. How does a wheat soil differ in mechanical structure from a truck soil? 15. A good corn soil is also a good type for what other crops? 16. How much water is required to produce an average grain crop, and how do the rainfall and the water removed in crops during the growing season compare? 17. In what forms may water be present in soils? 18. What is bottom water and when may it be utilized by crops? 19. What is capillary water? 20. Explain the capillary movement of water. 21. Explain how the capillary and non-capillary spaces in the soil may be influenced by cultivation. 22. What is hydroscopic water and of what value is it to crops? 23. What is percolation? 24. To what extent may losses occur by percolation? 25. What are the factors which influence evaporation? 26. What is transpiration? 27. In what three ways may water be lost from the soil? 28. Why does shallow surface cultivation prevent evaporation? 29. Why is it necessary to cultivate the soil after a rain? 30. Explain the movement of the soil water after a light shower. 31. What influence has rolling the land upon the moisture content of the soil? 32. What is subsoiling and how does it influence the moisture content of soils? 33. What influence does early spring plowing exert upon the soil moisture? 34. What is the action of a mulch upon the soil? 35. Why should different soils be plowed to different depths? 36. What is meant by the permeability of a soil? 37. How may cultivation influence permeability? 38. How may commercial fertilizers influence the water content of soils? 39. Explain the physical action of well-prepared farm manures upon the soil and their influence upon the soil water. 40. What is the object of good drainage? 41. Why does deforesting a region unfavorably influence the agricultural value of a country? 42. What are the sources of heat in soils? 43. To what extent does the color of soils influence the tem-

perature? 44. What is the specific heat of soils? 45. To what extent does drainage influence soil temperature? 46. How do manured and unmanured land compare as to temperature? 47. What relation does heat bear to crop growth? 48. What materials impart color to soils? 49. What is the effect of loss of organic matter upon the color of soils? 50. What materials impart taste to soils? Odor? 51. What effect does a weak current of electricity have upon crop growth? 52. Do all soils possess the same power to absorb gases? Why? 53. What is agricultural geology? 54. What agencies have taken part in soil formation? 55. How does the action of heat and cold aid in soil formation? 56. Explain the action of water in soil formation. 57. What is glacial action, and how has it been an important factor in soil formation? 58. Explain the action of vegetation upon soils. 59. How has the action of micro-organisms aided in soil formation? 60. Explain the terms: Sedentary, transported, alluvial, colluvial, volcanic, and windformed soils. 61. What is feldspar and what kind of soil does it produce? 62. Give the general composition of the following rocks and minerals and state the quality of soil which each produces: Granite, mica, hornblende, zeolites, kaolin, apatite, and limestone. 63. What elements are liable to be the most deficient in soils? 64. Name the acid- and base-forming elements present in soils. 65. What are the elements most essential for crop growth? 66. State some of the different ways in which the elements present in soils combine. 67. Why is it customary to speak of the oxides of the elements and to deal with them rather than with the elements? 68. Do the elements exist in the soil in the form of oxides? 69. What are double silicates? 70. In what forms does carbon occur in soils? 71. Is the soil carbon the source of the plant carbon? 72. What can you say regarding the occurrence and importance of the sulphur compounds? 73. What influence would 0.10 per cent. chlorine have upon the soil? 74. In what forms does phosphorus occur in soils? 75. What is the principal form in which the nitrogen occurs in soils? 76. What can be said regarding the hydrogen and oxygen of the soil? 77. State the principal forms and the value as plant food of the following elements: Aluminum, potassium, calcium, sodium, and iron. 78. For plant food purposes, what three divisions are made of the soil compounds? 79. Why are the complex silicates of no value as plant food? 80. Give the relative amounts of plant food in the three classes. 81. How is a soil analysis made? 82. What can be said regarding the economic value of a soil analysis? 83. What are some of the important facts to observe in interpreting results of soil analysis? 84. Under what conditions are the results most valuable? 85. Do the terms volatile matter and organic matter mean the same? 86. How may organic acids be employed in soil analysis? 87. Why are dilute organic acids used? 88. Is the plant food equally distributed in both surface and subsoil? 89. Do different grades of soil particles, from the same soil, have the same composition? 90. What are "alkali soils"? 91. Why is the alkali sometimes in the form of a crust? 92. Are all soils with white coating strongly alkaline? 93. Give the treatment for improving an alkali soil. 94. How may a small "alkali spot" be treated? 95. What are the sources of the organic compounds of soils? 96. How may the organic compounds of the soil be classified? 97. Explain the term humus. 98. How is the humus of the soil obtained? 99. What is humification? What is a humate? How are humates produced in the soil? 100. Explain how different materials produce humates of different value. 101. Arrange in order of agricultural value the humates produced from the following materials: Oat straw, sawdust, meat scraps, sugar, clover. 102. Of what value are the humates as plant food? 103. How much plant food is present in soils in humate forms? 104. What agencies cause a decrease of the humus content of soils? 105. To what extent does humus influence the physical properties of soils? 106. What is humic acid? 107. What soils are most liable to be in need of humus? When are soils not in need of humus? 108. In what ways does the humus of long-cultivated soils differ from that of new soils? 109. How may different methods of farming influence the humus content of soils? 110. What may be said regarding the importance of nitrogen as plant food? 111. What are the functions of nitrogen in plant nutrition? 112. How may the foliage indicate a lack or an excess of this element? 113. In what three ways did Boussingault conduct experiments relating to the assimilation of the free nitrogen of the air? 114. What were his results? 115. What conclusions did Ville reach? 116. Give the results of Lawes and Gilbert's experiments. 117. How did field results compare with laboratory experiments? 118. In what ways were the conditions of field experiments different from those conducted in the laboratory? 119. Give the results of Hellriegel's and Wilfarth's experiments. 120. What is noticeable regarding the composition of clover root nodules? 121. Of what agricultural value are the results of Hellriegel? 122. What is the source of the soil's nitrogen? 123. How may the organic nitrogen compounds of the soil vary as to complexity? 124. To what extent may the nitrogen in soils vary? 125. To what extent is nitrogen removed in crops? 126. To what extent are nitrates, nitrites, and ammonium compounds found in soils? 127. To what extent is nitrogen returned to the soil in rain-water. 128. How may the ratio of nitrogen to carbon vary in soils? Of what agricultural value is this ratio? 129. Under what conditions do soils gain in nitrogen content? 130. What methods of cultivation cause the most rapid decline in the nitrogen content of soils? 131. What is nitrification? 132. What are the conditions necessary for nitrification? and what are the food requirements of the nitrifying organism? 133. Why is oxygen necessary for nitrification? 134. How does temperature, moisture, and sunlight influence this process? 135. What part does calcium carbonate and other basic compounds take in nitrification? 136. How is nitrous acid produced? 137. What is denitrification? 138. What other organisms are present in soils besides those which produce nitrogen pentoxide, nitrogen trioxide, and ammonia? 139. What chemical products do these various organisms produce? 140. Why are soils sometimes inoculated with organisms? 141. Why does summer fallowing of rich lands cause a loss of nitrogen? 142. What influence have deep and shallow plowing, and spring and fall plowing upon the available soil nitrogen? 143. Into what three classes are nitrogenous fertilizers divided? 144. How is dried blood obtained? What is its composition, and how is it used? 145. What is tankage? How is it used, and how does it differ in composition from dried blood? 146. What is flesh meal? 147. What is fish scrap fertilizer, and what is its comparative value? 148. What seed residues are used as fertilizer? What is their value? 149. What method is employed to detect the presence of leather, hair, and wool waste in fertilizers? Why are these materials objectionable? 150. How may peat and muck be used as fertilizers? 151. What is sodium nitrate? How is it used, and what is its value as a fertilizer? 152. How does ammonium sulphate, as a fertilizer, compare in value with nitrate of soda? 153. What is the difference between the nitrogen content and the ammonia content of fertilizers? 154. What is fixation? Give an illustration. 155. To what is fixation due? 156. What part does humus take in fixation? 157. Why do soils differ in fixative power? Why are nitrates not fixed? 158. Why is fixation a desirable property of soils? 159. Why is it necessary to study the subject of fixation in the use of manures? 160. Why are farm manures variable in composition? 161. What is the distinction between the terms stable manure and farm-yard manure? 162. About what per cent. of nitrogen, phosphoric acid, and potash is present in ordinary manure? 163. Coarse fodders cause an increase of what element in the manure? 164. What four factors influence the composition and value of manure? 165. What influence do absorbents have upon the composition of manures? 166. What advantages result from the use of peat and muck as absorbents? 167. Compare the value of manure produced from clover with that from timothy hay. 168. How may the value of manure be determined from the nature of the food consumed? 169. To what extent is the fertility of the food returned in the manure? 170. Is much nitrogen added to the body during the process of fattening? 171. Explain the course of the nitrogen of the food during digestion and the forms in which it is voided in the manure. 172. Compare the solid and liquid excrements as to constancy of composition and amounts produced. 173. What is meant by the manurial value of food? 174. Name five foods with high manurial values; also five with low manurial values. 175. What is the usual commercial value of manures compared with commercial fertilizers? 176. How does the manure from young and from old animals compare as to value? 177. How much manure does a well-fed cow produce per day? 178. What are the characteristics of cow manure? How do horse manure and cow manure differ as to composition, character, and fermentability? 179. What are the characteristics of sheep manure? 180. How does hen manure differ from any other manure? 181. Why should the solid and liquid excrements be mixed to produce balanced manure? 182. What volatile nitrogen compound may be given off from manure? 183. What may be said regarding the use of human excrements as manure? 184. Is there any danger of an immediate scarcity of plant food to necessitate the use of human excrements as manure? 185. To what extent may losses occur when manures are exposed in loose piles and allowed to leach for six months? 186. What two classes of ferments are present in manure? 187. Explain the workings of the two classes of ferments found in manures. 188. How much heat may be produced in manure during fermentation? 189. Is water injurious to manure? 190. How should manure be composted? What is gained? 191. How does properly composted manure compare in composition with fresh manure? 192. Explain the action of calcium sulphate in the preservation of manure. 193. How does manure, produced in open barnyards, compare in composition with that produced in covered sheds? 194. When may manure be taken directly to the field and spread? 195. How may coarse manures be injurious to crops? 196. What is gained by manuring pasture land? 197. Is it economical to make a number of small manure piles in a field? Why? 198. At what rate per acre may manure be used? 199. To what crops is it not advisable to add stable manure? 200. How do a crop and a manure produced from that crop compare in manurial value? 201. Why do manures have such a lasting effect upon soils? 202. Why does manure from different farms have such variable values and composition? 203. In what seven ways may stable manures be beneficial? 204. What may be said regarding the importance of phosphorus as plant food? What function does it take in plant economy? 205. How much phosphoric acid is removed in ordinary farm crops? 206. To what extent is phosphoric acid present in soils? 207. What are the sources of the soil's phosphoric acid? 208. What are the commercial sources of phosphate fertilizers? 209. Give the four calcium phosphates and their relative fertilizer values. 210. Define reverted phosphoric acid. 211. Define available phosphoric acid. 212. In what forms do phosphate deposits occur? 213. State the general composition of phosphate rock. 214. Explain the process by which acid phosphates are made. Give reactions. 215. How is the commercial value of phosphoric acid determined? 216. What is basic phosphate slag and what is its value as a fertilizer? 217. What is guano? 218. How do raw bone and steamed bone compare as to field value? As to composition? 219. What is dissolved bone? 220. How is bone-black obtained, and what is its value as a fertilizer? 221. How are phosphate fertilizers applied to soils? In what amounts? 222. How may the phosphoric acid of the soil be kept in available condition? 223. What is the function in plant nutrition of potassium? 224. To what extent is potash removed in farm crops? 225. To what extent is potash present in soils? 226. What are the sources of the soil's potash? 227. What are the various sources of the potash used for fertilizers? 228. What are the Stassfurt salts, and how are they supposed to have been formed? 229. What is kainit? 230. How much potash is there in hard-wood ashes? 231. In what ways do ashes act on soils? 232. How do unleached ashes differ from leached ashes? 233. What is meant by the alkalimetry of an ash? 234. Of what value, as fertilizer, are hard- and soft-coal ashes? 235. What is the fertilizer value of the ashes from tobacco stems? 236. Cottonseed hulls? 237. Peat-bog ashes? 238. Saw-mill ashes? 239. Lime-kiln ashes? 240. How is the commercial value of potash determined? 241. How are potash fertilizers used? 242. Why is it sometimes necessary to use a lime fertilizer in connection with a potash fertilizer? 243. What can be said regarding the importance of lime as a plant food? 244. To what extent is lime removed in crops? 245. To what extent do soils contain lime? 246. What are the lime fertilizers? 247. Explain the physical action of lime fertilizers. 248. Explain the action of lime on heavy clays. 249. On sandy soils. 250. In what ways, chemically, do lime fertilizers act? 251. How may lime aid in liberating potash? 252. What is marl? 253. How are lime fertilizers applied? 254. What is the result when land plaster is used in excess? 255. Explain the action of salt on soils? 256. When would it be desirable to use salt as a fertilizer? 257. Is soot of any value as a fertilizer? Explain its action. 258. Are sea-weeds of any value as fertilizer? 259. What is a commercial fertilizer? An amendment? 260. To what does the commercial fertilizer industry owe its origin? 261. Why are commercial fertilizers so variable in composition? 262. Explain how a commercial fertilizer is made. 263. Why are the analysis and inspection of fertilizers necessary? 264. What are the usual forms of nitrogen in commercial fertilizers? 265. Of phosphoric acid and potash? 266. How is the value of a commercial fertilizer determined? 267. What is gained by home mixing of fertilizers? 268. What can be said about the importance of tillage when fertilizers are used? 269. How are commercial fertilizers sometimes injudiciously used? 270. How may field tests be conducted to determine a deficiency in available nitrogen, phosphoric acid, or potash? 271. To determine a deficiency of two elements? 272. How are the preliminary results verified? 273. Why is it essential that field tests with fertilizers be made? 274. Under what conditions does it pay to use commercial fertilizers? 275. What is the result when commercial fertilizers are used in excessive amounts? 276. Under ordinary conditions, what special help do the following crops require: Wheat, barley, corn, potatoes, mangels, turnips, clover, and timothy? 277. In what ways do commercial fertilizers and farm manures differ? 278. Does the amount of fertility removed by crops indicate the nature of the fertilizer required? In what ways are plant ash analyses valuable? 279. Explain the action of plants in rendering their own food soluble. 280. Why do crops differ as to their power of procuring food? 281. Why is wheat less liable to need potash than nitrogen? 282. What position should wheat occupy in a rotation? 283. In what ways do wheat and barley differ in feeding habits? 284. What can be said regarding the food requirements of oats? 285. Corn removes from the soil twice as much nitrogen as a wheat crop, yet a wheat crop usually thrives after a corn crop. Why? 286. What help is corn most liable to need in the way of food? 287. What position should flax occupy in a rotation? 288. On what soils does flax thrive best? 289. What is the essential point to observe in the manuring of potatoes? 290. What kind of manuring do sugar-beets require? 291. Why should the manuring of mangels be different from that of turnips? 292. What may be said regarding the food requirements of buckwheat and rape? 293. What kind of manuring do hops and cotton require? 294. What kind of manuring is most suitable for leguminous crops? 295. What is the object of rotating crops? 296. Should the whole farm undergo the same rotation system? 297. What is meant by soil exhaustion? 298. What are the nine important principles to be observed in a rotation? 299. Explain why it is essential that deep and shallow rooted crops should alternate. 300. Why is it necessary that the humus be considered in a rotation? 301. What is the object of growing crops of dissimilar feeding habits? 302. How may crop residues be used to the best advantage? 303. In what ways may a decline of soil nitrogen be prevented by a good rotation of crops? 304. In what ways do different crops and their cultivation influence the mechanical condition of the soil? 305. How may the best use be made of the soil water? 306. How may a rotation make an even distribution of farm labor? 307. How are manures used to the best advantage in a rotation? 308. In what other ways are rotations advantageous? 309. What may be said regarding long- and short-course rotations? 310. How is the conservation of fertility best secured? 311. Why does the use made of crops influence fertility? 312. What are the essential points to be observed in the two systems of farming compared in Section 323? 313. Is it essential that all elements removed in crops should be returned to the soil in exactly the amounts contained in the crops? Why? 314. How does manure influence the inert matter of the soil? 315. What general systems of farming best conserve fertility? 316. Under what conditions may farms be gaining in reserve fertility? 317. Why in continued grain culture does the loss of nitrogen from a soil exceed the amount removed in the crop?

CORRECTIONS

Page 25, line 19, for "three months," read "two months."

Page 28, line 18, after soil, add : "absorbed from the air."

Page 28, line 26, add : "when reduced below 4 per cent."

Page 64, line 5, for "one-half," read "one-tenth."

Page 72, line 18, read "94," not "96."

Page 150, line 2, read "clover hay nitrogen, 35," not "45."

Page 187, under Flax, transpose "19" and "8."

INDEX

NOYES.

Organic Chemistry for the Laboratory.—By W. A. NOYES, PH.D., Professor of Chemistry in Rose Polytechnic Institute, Terre Haute, Ind. - - - - - - - - $1.50

NOYES AND MULLIKEN.

Laboratory Experiments on the Class Reactions and Identification of Organic Substances.—By ARTHUR A. NOYES, PH.D., Associate Professor of Organic Chemistry in the Massachusetts Institute of Technology, and SAMUEL P. MULLIKEN, PH.D., Instructor in Organic Chemistry in the Massachusetts Institute of Technology. Second, Thoroughly Revised Edition - $ .50

SNYDER.

The Chemistry of Dairying.—By HARRY SNYDER, B.S., Professor of Chemistry in the University of Minnesota - $1.50

An Outline of the Chemical and Allied Changes which take place in Milk and in the Manufacture of Butter and Cheese; and the Rational Feeding of Dairy Stock.

STILLMAN.

Engineering Chemistry.—By THOMAS B. STILLMAN, Professor of Analytical Chemistry in the Stevens Institute of Technology. A Manual of Quantitative Chemical Analysis for the use of Students, Chemists, and Engineers - - - - - $4.50

8vo. Cloth. 154 Illustrations.

VENABLE.

The Development of the Periodic Law.—By F. P. VENABLE, Professor of Chemistry in the University of North Carolina. - - - - - - - - - - - - $2.50

12mo. Cloth. Well Illustrated.

VENABLE AND HOWE.

Inorganic Chemistry According to the Periodic Law.—By F. P. VENABLE, University of North Carolina, and JAS. LEWIS HOWE, Washington and Lee University - - - - $1.50

Cloth. 35 Illustrations.

WILEY.

Principles and Practice of Agricultural Chemical Analysis.—By HARVEY W. WILEY, Chemist of the U. S. Department of Ag-

Aaron Bldg.

Snyder

Chemistry of soils and

E631.4-Sn9c 457